5.0 DATA

5.1 SURFACE WATER

5.1.1 Perchlorate Occurrence in Streams

5.1.1.1 Stream Water Grab Samples

5.1.1.1.1 Introduction

In order to better characterize the potential points of exposure within the study area, grab samples of surface water were collected periodically and specifically to coincide with sampling of biota. Samples were collected in order to evaluate perchlorate exposure to mammals, birds, fish, and amphibians; however, these samples were not meant to characterize the spatial and temporal variation in perchlorate concentrations within surface water in the Lake Belton and Lake Waco watersheds. In addition, grab samples provided a mechanism to evaluate the potential movement of perchlorate from surface water to terrestrial environments through vegetation and/or other routes of trophic transfer.

5.1.1.1.2 Methodology

Stream water grab samples were collected from various locations within the study area (35 locations). Sample locations were chosen to include both "reference" areas (no perchlorate contamination suspected) and "contaminated" areas (suspect areas based on historical data and watershed hydrology). The 35 locations from which surface water samples were collected are identified in **Figure 5-1** and described in **Table 5-1**.

Water samples were collected in pre-cleaned glass vials (20 mL) from the surface of the water body. GPS coordinates of sample locations were recorded at the time of sampling. Water samples were placed on ice during transport back to the laboratory and stored at 4 °C until analysis by ion chromatography (**Appendix X**). Within this section and throughout the entire document, all perchlorate concentrations are expressed as the concentration of the perchlorate anion (ClO_4^-) only; the ammonium counterion is not included in the concentration expression.

5.1.1.1.3 Data

Analytical results of surface water grab samples collected beginning in March 2001 are included in **Appendix C**. Perchlorate residue data for selected sites are also presented graphically in **Appendix C**. Several exposure points within the study area were identified through this sampling effort including (1) the spring on Oglesby Road, (2) Station Creek south of the NWIRP property, (3) S Creek at Highway 317, and (4) the Unidentified tributary near the wastewater treatment plant (WWTP) at Highway 317.

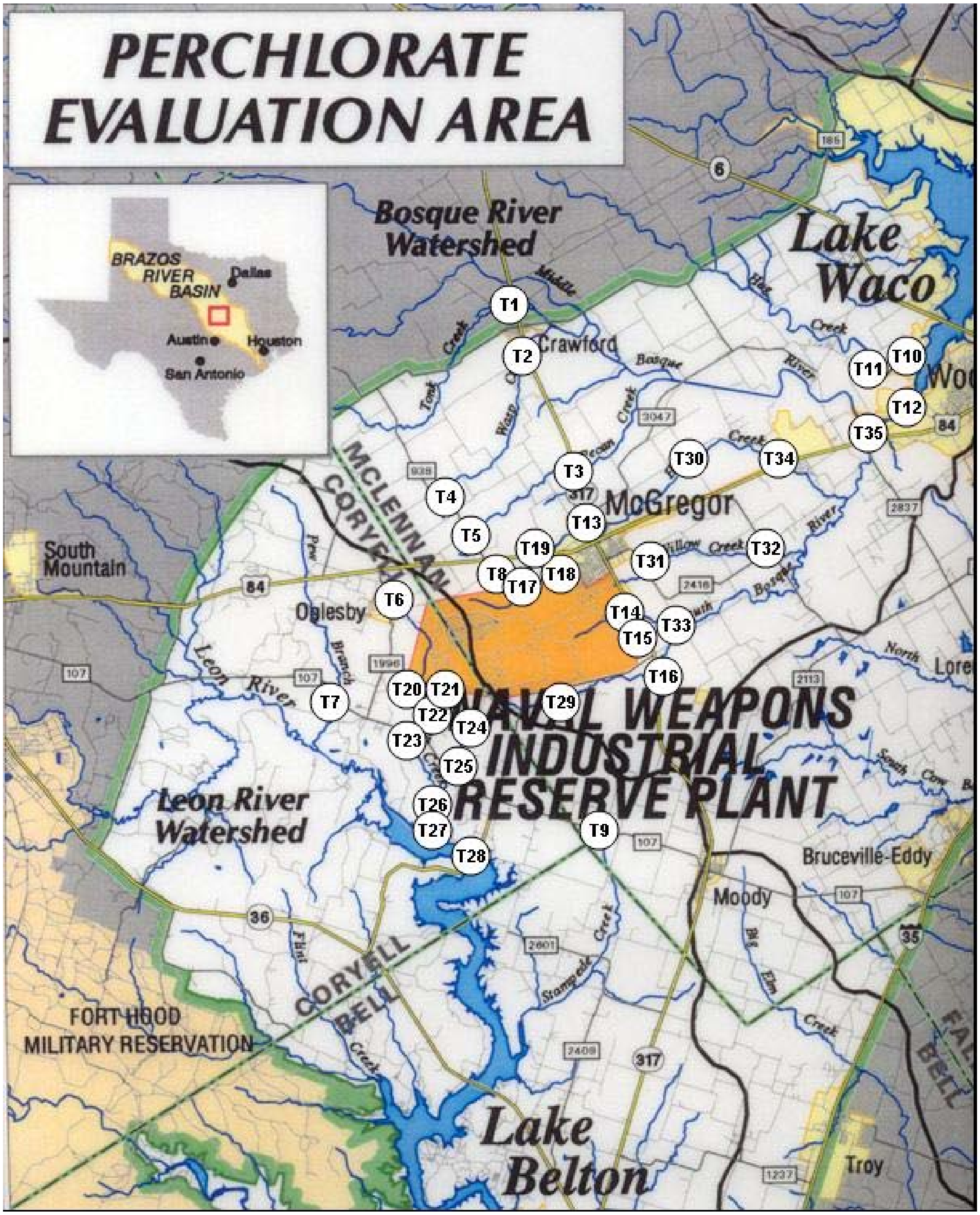


Figure 5-1
Map of Study Area Illustrating the Approximate Locations Where Surface Water Grab Samples Were Collected

Table 5-1
Locations of Stream Water Grab Samples

Location Type	ID[a]	Location Description	UTM
Reference Sites	T1	Tank Creek at Highway 317	647618E 3490671N
	T2	Wasp Creek at Highway 317	648033E 3488680N
	T3	Pecan Creek at Highway 317	650195E 3483242N
	T4	Wasp Creek at FM 938	644411E 3482032N
	T5	Pecan Creek at FM 938	645673E 3479993N
	T6	Station Creek at Oglesby Road	642344E 3477044N
	T7	Pew Branch at Highway 107	639323E 3472938N
	T8	Harris Creek at Oglesby Road North	647790E 3478770N
	T9	Stampede Creek at Highway 107	650859E 3466885N
	T10	Hog Creek	664928E 3487889N
	T11	Hog Creek 2	664146E 3487661N
	T12	Middle Bosque near Highway 84	664464E 3485354N
Sites down-gradient from NWIRP	T13	Harris Creek at Highway 317	651046E 3480160N
	T14	Unnamed Tributary near WWTP at Highway 317	652853E 3476589N
	T15	S Creek at Highway 317	653646E 3474993N
	T16	South Bosque at Highway 317	653810E 3473908N
	T17	Harris Creek at Oglesby Road	648178E 3478942N
	T18	Spring on Oglesby Road	649218E 3479243N
	T19	Harris Creek at Highway 84 West of McGregor	649100E 3479383N
	T20	Station Creek near the NWIRP Boundary	643318E 3472885N
	T21	Station Creek near the NWIRP Boundary 2	643351E 3472742N
	T22	Tributary Feeding Station Creek near NWIRP Boundary	643736E 3472922N
	T23	Station Creek at Highway 107 (T23)	642988E 3471304N
	T24	Onion Creek North of Highway 107	645534E 3472063N
	T25	Onion Creek at Highway 107	644703E 3469668N
	T26	Station Creek at Old River Road	643925E 3466457N
	T27	Station Creek at Leon River	644516E 3466167N
	T28	Leon River at Mother Neff Park	645312E 3465366N
	T29	South Bosque West of Highway 317	650074E 3473895N
	T30	Harris Creek at Windsor Road	653243E 3401660N
	T31	Willow Creek at Highway 2416	653479E 3478494N
	T32	Willow Creek 2 at Highway 2416	655924E 3478058N
	T33	South Bosque at Indian Trail	655034E 3476011N
	T34	Harris Creek at Highway 84 near the Executive Airport	659529E 3483444N
	T35	South Bosque at Highway 84	664177E 3484767N

[a]see **Figure 5-1** for approximate locations.

5.1.1.1.4 Discussion

Historical data and several months of periodic sampling of surface water in and around the study area provided some details as to where perchlorate exposures had the highest potential to occur:

- Station Creek south of NWIRP (T20-T23)
- The spring on Oglesby Road (T18)
- Harris Creek from Highway 84 to areas east of McGregor (T19, T13)

- An unnamed tributary near the wastewater treatment plant at Highway 317 (T14)
- S Creek at Highway 317 (T15)

The highest perchlorate concentrations (range = 67 - 540 ppb) were consistently observed in S Creek near Highway 317 (T15). Overall, perchlorate contamination of surface water within the study area varies with location, season, and rainfall conditions, with the exception of the spring on Oglesby Road (T18) (range = 26 - 67 ppb). Most of these surface water bodies were surrounded by vegetation (likely exposure pathway to terrestrial animals) and supported aquatic life (potential exposure pathway to humans). The spring on Oglesby Road (T18) had surface water flow most of the year, serving as a source of exposure even during drought periods. Property access indicated that larger mammals (beef cattle) also used the spring water on this site, as well as areas surrounding Station Creek near the NWIRP property (T20-T22).

5.1.1.2 Auto Samples

5.1.1.2.1 Introduction

Fifteen automated surface water monitoring stations were installed along streams that discharge to Lake Waco and Lake Belton as described in Section 4.1.1. Each monitoring station was programmed to collect surface water samples and to measure and record stream level and rainfall data. These monitoring stations are listed in **Table 5-2** and their locations are shown on **Plate 1**.

Table 5-2
Longitudinal Stream Monitoring Station Locations

Station ID	Location	Lake discharged to by Stream
SC1	Station Creek at A&M Property	Lake Belton
TRM1	Tributary M at A&M Property	Lake Belton
SC3	Station Creek at 107	Lake Belton
OC1	Onion Creek at 107	Lake Belton
SC5	Station Creek at Oglesby Neff Park Road	Lake Belton
LR1	Leon River at 236	Lake Belton
HC1	Harris Creek at Middle Windsor Road	Lake Waco
HC2	Harris Creek near Val Verde Road	Lake Waco
SBR3	South Bosque River at Church Road	Lake Waco
SBR1	South Bosque River at Indian Trail	Lake Waco
SBR2	South Bosque River near Cottonbelt Parkway	Lake Waco
SBR4	South Bosque River near Ruff Road	Lake Waco
SBR5	South Bosque River at 84	Lake Waco
MBR1	Middle Bosque River, downstream of intersection of South Bosque River	Lake Waco
CHC1	Cowhouse Creek at Tank Destroyer Road	Lake Belton

The monitoring stations were installed to collect perchlorate concentration data and associated stream level data at various points along each stream to determine what concentrations and flow may be entering Lake Waco and Lake Belton from each of the streams. The Cowhouse Creek monitoring station was used to help determine if runoff from Fort Hood contributes perchlorate to Lake Belton. All sampling methodologies and protocols followed during the Study are detailed in the *Final Longitudinal Stream Sampling Study Field Sampling Plan* (MWH, 2002b). Deviations from the Field Sampling Plan are discussed further below.

5.1.1.2.2 Methodology

Each auto sampler was programmed to collect periodic grab surface water samples for perchlorate analysis. Samples were collected at the same time during most sampling events. However, to evaluate a variety of hydrologic scenarios, grab sampling at different times as well as sampling in conjunction with rainfall was also performed. The surface water samples were collected in plastic sample bottles and were stored within the auto sampler until retrieved by the field crew. In addition to the grab samples, stream level and rainfall data were collected every 15 minutes. Level and rainfall data are discussed in later sections.

Equipment. The following equipment was installed at each of the 15 automated monitoring station locations, except as noted below:

- ISCO 4230 Flow Meter (equipped with a bubbler and a rain gauge). No rain gauge was installed in station SBR5 (South Bosque River at US 84) because the station was located under a bridge.
- ISCO 6712 Auto Sampler.
- PVC pipe to run sample tubing and bubbler to the center of the stream.
- 12-volt battery and solar panel to recharge the battery.
- An additional data logger to store groundwater-elevation data from nearby monitoring well (monitoring well information is presented in Section 5.1.3).
- A protective portable steel enclosure to house the flow meter, auto sampler, battery, and data logger.

Photographs of typical automated stream sampling stations are shown in **Figure 5-2**, **Figure 5-3**, and **Figure 5-4**.

Figure 5-2
Typical Longitudinal Stream Sampling Station with Monitoring Well

Figure 5-3
Rain Gauge and Flow Meter at a Station

Figure 5-4
PVC Pipe Containing Bubbler for Level and Strainer for Stream Sampling

Standard Sampling. The ISCO sampler was programmed to collect data at the following frequencies under standard sampling conditions:

- Once daily for the first 15 days.
- Once weekly for the next three weeks
- Once every two weeks for the remainder of the study (i.e., 12 months).

During standard bi-weekly surface water sampling, the field crew visited the sampling stations at least every 14 days to collect samples, reload the auto sampler, download data from the data loggers, check the operation of the metering station and equipment, and perform any needed maintenance activities. The field crew attempted to pick up and ship the samples within 24 hours of sample collection.

Storm Event Sampling. Storm sampling was necessary to determine how perchlorate concentrations in the study area streams may vary based on increased surface water and "first flush" groundwater flows that occur immediately after a storm event. Factors that contribute to defining a significant storm event included rainfall (total and duration), and change in stream level.

During storm event sampling, the automated monitoring stations were taken out of standard sampling mode and were reprogrammed to detect rainfall in the rain gauge and automatically start sampling during a significant storm event. The standard sampling during this time was conducted by utilizing the "manual" function on the autosampler.

After evaluating the various types of storms that occur in the study area and gathering stream flow, groundwater level and rainfall data for a period of time to better understand the interaction of rainfall, stream height, and depth to groundwater, a significant storm criteria was determined as 0.1 inches of rain within a 15-minute time period. Discussions with ISCO, the equipment vendor, verified this determination as a typical criterion used for determining storm events in Texas. Each sampler was programmed to collect samples every four hours for 14 days. The samples were picked up as frequently as possible, at a minimum of every three days. Two storm events were studied during the course of the study: May 1 through May 16, 2003 and September 11 through October 2, 2003.

Duplicate Samples. Blind duplicate samples were collected at all sampling locations at a frequency to represent 10% of the environmental samples collected and MS/MSD samples were collected at a frequency to represent 5% of the environmental samples collected.

Sample Designation. Each surface water sample was designated with an alphanumeric character string set apart by hyphens. The designation began with the stream name abbreviation and monitoring station number (e.g., "SBR1" for South Bosque River monitoring station 1, "HC1" for Harris Creek monitoring station 1, etc.), followed by "SW" to indicate a surface water sample, and finally by the date and military time the sample was collected. For example, the surface water sample collected from Station Creek monitoring station 1 at 16:15 on November 18, 2002 was designated "SC1- SW-11-18-1615".

Blind duplicate samples were designated with a fictitious number so that the laboratory was unaware of where the sample was taken. For example, the blind duplicate sample collected with environmental sample "SC1-SW-11-18-1615" was designated "SW-1001". The field crew kept careful records of the designations given to the blind duplicate samples and their corresponding environmental sample so that the analytical results could be correlated when they were received. Each MS/MSD sample had the same designation as its associated environmental sample except that "MS" or "MSD" followed the sample designation (e.g., "SC1-SW-11-18-1615 MS" and "SC1-SW-11-18-1615 MSD").

Sampling Comments. If a sample was not collected because the sample intake was above the water level, the sample was designated as "Dry". If a sample was not collected due to equipment error, the sample was designated as "Equipment Error". The holding time for perchlorate is 28 days, but most samples were collected within 24 hours. When samples were not picked up within 24 hours, the samples were marked as "> 24 Hours" for quality tracking purposes.

Sample Analysis. All surface water samples were analyzed for perchlorate by USEPA Method 314.0 at the USACE Engineer Research and Development Center Environmental Laboratory at the Environmental Chemistry Branch in Omaha, Nebraska. (See **Appendix V**). The data verification report for the samples analyzed is included in **Appendix W**.

Field Observations. The field crew also collected the following field observations during each visit to each sampling station.

- Cloud cover
- Wind velocity
- Secchi Disk transparency
- Water color
- Aquatic vegetation in percent cover
- Instantaneous flow rate.

In addition, the following field measurements were obtained through the use of a Hydrolab Mini Sonde 4a (multi-parameter instrument):

- Temperature
- Dissolved oxygen
- Specific conductance
- pH
- Salinity
- Dissolved oxygen percent saturation.

The field observations and Hydrolab water quality data collected as part of this study are presented in **Appendix D**.

<u>5.1.1.2.3 Data</u>

This section summarizes the perchlorate analytical data collected over the course of the study at each automated monitoring station location. As previously discussed, the former NWIRP McGregor plant is located on a topographic high near the confluence of four watersheds. The divide for two of these watersheds, the Leon River watershed and the Bosque River watershed is located on the plant site. Based on this watershed divide, contaminants located in the southwest section of the plant drain into local streams within the Leon River watershed, to the Leon River and finally into Lake Belton. Surface and groundwater from all other plant locations drain into local streams that flow into the Middle Bosque River and then into Lake Waco. For ease of discussion and understanding, the stream network has been divided into two stream segment study areas (NWIRP to Lake Belton and NWIRP to Lake Waco) and will be discussed moving from upstream to downstream in the following sections. An additional tributary to Lake Belton, Cowhouse Creek, was also evaluated during this study to determine if runoff from Fort Hood might be contributing detectable concentrations of perchlorate to Lake Belton.

Bi-weekly and storm samples from streams were collected throughout the study from October 17, 2002 to October 2, 2003. Bi-weekly samples were collected from October 17, 2002 to August 28, 2003. Data were also collected during two storm events during this study. The first set of storm sampling data were collected between May 1, 2003 and May 16, 2003, and the second set of storm sampling data were collected between September 11, 2003 and October 2, 2003.

5.1.1.2.3.1 Biweekly Sampling

This section summarizes data from the biweekly sampling conducted at all the automated monitoring stations. Samples that had perchlorate concentrations below the MDL (<1 µg/L) are reported as "<1 µg/L" in the data tables and are plotted at 0.5 µg/L on the data plots. Similarly, the average perchlorate concentration presented for each station was calculated using 0.5 µg/L for samples that were below the MDL (<1 µg/L). Refer to **Appendix E** for tables and plots of bi-weekly sampling data at all of the stations.

5.1.1.2.3.1.1 NWIRP to Lake Belton

Station Creek at A&M property (SC1)

Monitoring station SC1 is located on Station Creek, approximately 0.4 mile downstream of the NWIRP boundary, on the Texas A & M property. The project team attempted to collect 48 samples as part of the bi-weekly sampling from October 17, 2002 to August 28, 2003. Of these samples, one sample could not be collected due to the site being dry. Perchlorate was not detected in any of the 47 samples (100 percent) collected. The bi-weekly perchlorate data table and plot for this station are included in **Appendix E**.

Tributary M at A&M property (TRM1)

Monitoring station TRM1 is located on Tributary M (informal name) on the Texas A& M property just off the NWIRP property. The project team attempted to collect 52 samples at this location as part of the bi-weekly sampling from October 17, 2002 to August 28, 2003. Of these samples, five samples could not be collected because the site was dry, and two samples could not be collected due to equipment error. Perchlorate was not detected in 10 of the samples collected (22.2 percent). Perchlorate concentrations in three of the samples collected (6.7 percent) ranged between the MDL (1 µg/L) and the RL (4 µg/L) and were flagged as estimated values. Perchlorate concentrations in 32 samples ranged between the RL (4 µg/L) and 111 µg/L. The average perchlorate concentration at this site was 10.1 µg/L and the maximum perchlorate concentration was 111 µg/L. The bi-weekly perchlorate data table and plot for this station are included in **Appendix E**.

Station Creek at 107 (SC3)

Monitoring station SC3 is located where State Highway 107 crosses Station Creek. This location is approximately one mile downstream of the intersection of Tributary M and Station Creek and is approximately 1.5 miles downstream from the NWIRP boundary along Station Creek. The project team attempted to collect a total of 42 samples as part of the bi-weekly sampling from October 17, 2002 to August 28, 2003. Of these samples, one sample could not be collected due to the site being dry, and four samples could not be collected due to equipment error. Perchlorate was not detected in seven samples (18.9 percent) of the samples collected. Perchlorate concentrations in 14 of the samples collected (37.8 percent) ranged between the MDL (1 µg/L) and the RL (4 µg/L) and are flagged as estimated. Perchlorate concentrations in 16 samples ranged between the RL (4 µg/L) and 38 µg/L. The average perchlorate concentration at this site was 5.11 µg/L, and the maximum perchlorate concentration was 38 µg/L. The bi-weekly perchlorate data table and plot for this station are included in **Appendix E**.

Onion Creek at 107 (OC1)
Monitoring station OC1 is located where Highway 107 crosses Onion Creek, approximately 2.2 miles downstream of the NWIRP boundary. The project team attempted to collect a total of 47 samples as part of the bi-weekly sampling from October 17, 2002 to August 28, 2003. Of these samples, three samples could not be collected due to the site being dry. Perchlorate was not detected in 43 samples (97.7 percent) of the samples collected. The perchlorate concentration in one sample (2.3 percent) was between the MDL (1 µg/L) and the RL (4 µg/L) and is flagged as estimated. No samples had perchlorate concentrations above the RL (4 µg/L). The average perchlorate concentration at this site was 0.56 µg/L, and the maximum perchlorate concentration at this site was 3 µg/L. The maximum perchlorate concentration was detected in a duplicate sample collected on October 30, 2002. No perchlorate was detected in the original sample. The bi-weekly perchlorate data table and plot for this station are included in **Appendix E**.

Station Creek at Oglesby Neff Park Road (SC5)
Monitoring station SC5 is located on Station Creek near Oglesby Neff Park Road. This station is near the confluence of Station Creek and the Leon River, approximately 5.2 miles downstream of the NWIRP boundary and 1.4 miles downstream of the intersection of Onion Creek and Station Creek. This stream discharges into the Leon River. The project team attempted to collect a total of 39 samples as part of the bi-weekly sampling from October 17, 2002 to August 28, 2003. Of these samples, 14 samples could not be collected due to the site being dry, and three samples could not be collected due to equipment error. Perchlorate was not detected in two (9.1 percent) of the samples collected. Perchlorate concentrations in 14 samples (63.6 percent) ranged between the MDL (1 µg/L) and the RL (4 µg/L) and are flagged as estimated. Perchlorate concentrations in six samples ranged between the RL (4 µg/L) and 7.6 µg/L. The average perchlorate concentration at this site was 2.73 µg/L, and the maximum perchlorate concentration was 7.6 µg/L. The bi-weekly perchlorate data table and plot for this station are included in **Appendix E**.

Leon River at 236 (LR1)
Monitoring station LR1 is located at the intersection of the Leon River and State Highway 236, approximately 6.5 miles downstream of the NWIRP boundary along Station Creek. The Leon River flows directly into Lake Belton. The project team attempted to collect a total of 37 samples as part of the bi-weekly sampling from October 17, 2002 to August 28, 2003. Of these, one sample could not be collected due to equipment error. Perchlorate was not detected in any of the 36 samples (100 percent) collected. The bi-weekly perchlorate data table and plot for this station are included in **Appendix E**.

5.1.1.2.3.1.2 NWIRP to Lake Waco

Harris Creek at Middle Windsor Road (HC1)

Monitoring station HC1 is located at the intersection of Harris Creek and Middle Windsor Road just outside the city boundary of McGregor, Texas, approximately 3.6 miles downstream of the NWIRP boundary along Harris Creek. The project team collected a total of 43 samples as part of the bi-weekly sampling from October 17, 2002 to August 17, 2003. Perchlorate was not detected in 21 (48.8 percent) of the samples collected. Perchlorate concentrations in 15 samples (34.9 percent) ranged between the MDL (1 µg/L) and the RL (4 µg/L) and are flagged as estimated. Perchlorate concentrations in seven samples ranged between the RL (4 µg/L) and 6.5 µg/L. The average perchlorate concentration at this site was 1.81 µg/L and the maximum concentration was 6.5 µg/L. The bi-weekly perchlorate data table and plot for this station are included in **Appendix E**.

Harris Creek near Val Verde Road (HC2)

Monitoring station HC2 is located on Harris Creek, approximately 7.2 miles downstream of the NWIRP boundary along Harris Creek, near Val Verde Road. The project team attempted to collect a total of 42 samples as part of the bi-weekly sampling from October 17, 2002 to August 28, 2003. Of these samples, one sample could not be collected due to the site being dry, and one sample could not be collected due to equipment error. Perchlorate was not detected in 22 (55.0 percent) of the samples collected. Perchlorate concentrations in 16 samples (40.0 percent) ranged between the MDL (1 µg/L) and the RL (4 µg/L) and are flagged as estimated. Two samples collected had perchlorate concentrations between the RL (4 µg/L) and 4.8 µg/L. The average perchlorate concentration at this site was 1.25 µg/L and the maximum perchlorate concentration was 4.8 µg/L. The bi-weekly perchlorate data table and plot for this station are included in **Appendix E**.

South Bosque River at Church Road (SBR3)

Monitoring station SBR3 is located on the South Bosque River at its intersection with Church Road, approximately 12 miles downstream of the NWIRP boundary. The project team attempted to collect a total of 36 samples as part of the bi-weekly sampling from October 17, 2002 to August 28, 2003. Of these, six samples could not be collected due to equipment error. Perchlorate was not detected in 21 (70.0 percent) of the samples collected. Perchlorate concentrations in nine samples (30.0 percent) ranged between the MDL (1 µg/L) and the RL (4 µg/L) and are flagged as estimated. No samples had perchlorate concentrations above the RL (4 µg/L). The average perchlorate concentration at this site was 0.88 µg/L, and the maximum perchlorate concentration was 2 µg/L. The bi-weekly perchlorate data table and plot for this station are included in **Appendix E**.

South Bosque River at Indian Trail (SBR1)

Monitoring station SBR1 is located at the intersection of the South Bosque River and Indian Trail Road, approximately 1.6 miles downstream of the NWIRP boundary. The project team attempted to collect a total of 38 samples as part of the bi-weekly sampling from October 17, 2002 to August 28, 2003. Of these, three samples could not be collected due to equipment error. Perchlorate was not detected in seven samples (20.0 percent) of the samples collected. Perchlorate concentrations in 16 samples (45.7 percent) ranged between the MDL (1 µg/L) and the RL (4 µg/L) and are flagged as estimated. Perchlorate concentrations in twelve samples collected ranged between the RL (4 µg/L) and 4.7 µg/L. The average perchlorate concentration at this site was 2.73 µg/L, and the maximum perchlorate concentration was 4.7 µg/L. The bi-weekly perchlorate data table and plot for this station are included in **Appendix E**.

South Bosque River near Cotton Belt Parkway (SBR2)

Monitoring station SBR2 is located on the South Bosque River near Cotton Belt Parkway, approximately 6.4 miles downstream of the NWIRP boundary. The project team attempted to collect a total of 36 samples as part of the bi-weekly sampling from October 17, 2002 to August 28, 2003. Of these samples, one sample could not be collected due to equipment error. Perchlorate was not detected in 16 (45.7 percent) of the samples collected. Perchlorate concentrations in 19 samples of the samples collected (54.3 percent) were between the MDL (1 µg/L) and the RL (4 µg/L) and are flagged as estimated. No samples had perchlorate concentrations above the RL (4 µg/L). The average perchlorate concentration at this site was 1.51 µg/L, and the maximum perchlorate concentration was 3 µg/L. The bi-weekly perchlorate data table and plot for this station are included in **Appendix E**.

South Bosque River near Ruff Road (SBR4)

Monitoring station SBR4 is located on the South Bosque River near Ruff Road, approximately 10 miles downstream of the NWIRP boundary. The project team attempted to collect a total of 41 samples as part of the bi-weekly sampling from October 17, 2002 to August 28, 2003. Of these samples, four samples could not be collected due to equipment error and one sample was broken in shipment. Perchlorate was not detected in 23 (63.9 percent) of the samples collected. Perchlorate concentrations in 13 of the samples collected (36.1 percent) ranged between the MDL (1 µg/L) and the RL (4 µg/L) and are flagged as estimated. No samples had perchlorate concentrations above the RL (4 µg/L). The average perchlorate concentration at this site was 1.10 µg/L, and the maximum perchlorate concentration was 3 µg/L. The bi-weekly perchlorate data table and plot for this station are included in **Appendix E**.

South Bosque River at 84 (SBR5)

This monitoring station is located on the South Bosque River at its intersection with Highway 84, approximately 13.2 miles downstream of the NWIRP boundary along the South Bosque. This stream discharges into the Middle Bosque River. The project team attempted to collect a total of 38 samples as part of the bi-weekly sampling from October 17, 2002 to August 28, 2003. Of these samples, three samples could not be collected due to equipment error. Perchlorate was not detected in 25 (71.4 percent) of the samples collected. Perchlorate concentrations in 10 of the samples collected (28.6 percent) ranged between the MDL (1 µg/L) and the RL (4 µg/L) and are flagged as estimated. No samples had perchlorate concentrations above the RL (4 µg/L). The average perchlorate concentration at this site was 0.81 µg/L and the maximum perchlorate concentration was 2 µg/L. The bi-weekly perchlorate data table and plot for this station are included in **Appendix E**.

Middle Bosque River (MBR1)
Monitoring station MBR1 is located on the Middle Bosque River approximately 14 miles downstream of the NWIRP boundary along the South Bosque. It is downstream of the intersection of South Bosque River and Highway 84. The Middle Bosque River discharges directly into Lake Waco. The project team attempted to collect a total of 37 samples as part of the bi-weekly sampling from October 17, 2002 to August 28, 2003. Of these, two samples could not be collected due to equipment error. Perchlorate was not detected in 35 (100 percent) of the samples collected. The bi-weekly perchlorate data table and plot for this station are included in **Appendix E**.

5.1.1.2.3.1.3 Cowhouse Creek at Tank Destroyer Road (CHC1)

Monitoring station CHC1 is located on Cowhouse Creek at the intersection of Tank Destroyer Road, before Cowhouse Creek discharges into Lake Belton. The project team collected a total of 38 samples as part of the bi-weekly sampling from October 17, 2002 to August 28, 2003. Of these samples, one sample was broken in shipment. Perchlorate was not detected in 37 (100 percent) of the samples collected. The bi-weekly perchlorate data table and plot for this station are included in **Appendix E**.

5.1.1.2.3.2 Storm Sampling

The first storm-sampling event was started on May 1, 2003 (summer season) when most of the streams were flowing and groundwater levels were high. The second storm-sampling event was started on September 11, 2003 (fall season), when most of the streams were dry and the groundwater level was among the lowest encountered in the year. The exact time storm sampling was triggered at each station depended on the rainfall at that location. Some stations did not trigger automatically due to tree cover or due to being located under a bridge and were manually started by the project team. Even during a storm event, there were samples that had to be designated as “dry” because there was insufficient water to collect a sample. The following is a summary of the storm sampling collected at each of the automated monitoring stations. As with preceding sections, the monitoring station results are discussed in order from upstream to downstream. The average perchlorate concentration reported for each station was calculated assuming a value of 0.5 μg/L for all samples below the MDL (<1 μg/L). Refer to **Appendix F** for tables and plots of perchlorate data during the first storm-sampling event and to **Appendix G** for tables and plots of perchlorate data during the second storm-sampling event. Samples that had perchlorate concentrations below the MDL (<1 μg/L) are listed as “<1 μg/L” in the data table and are plotted at 0.5 μg/L on the graphs.

5.1.1.2.3.2.1 NWIRP to Lake Belton

Station Creek at A&M property (SC1)
The project team collected a total of 93 samples as part of the storm sampling from May 1, 2003 to May 16, 2003. Perchlorate was not detected in any of the samples collected. The perchlorate data table and plot for this station during this storm event are included in **Appendix F**.

The project team attempted to collect a total of 116 samples as part of the storm sampling from September 11, 2003 to October 2, 2003. None of these samples could be collected because the site was dry. The perchlorate data table and plot for this station during this storm event are included in **Appendix G**.

Tributary M at A&M property (TRM1)
The project team collected a total of 92 samples as part of the storm sampling from May 1, 2003 to May 16, 2003. Six of these samples could not be analyzed because the samples were broken during shipment. Perchlorate was not detected in 86 samples (100 percent) of the samples analyzed. The perchlorate data table and plot for this station during this storm event are included in **Appendix F**.

The project team attempted to collect a total of 122 samples as part of the storm sampling from September 11, 2003 to October 2, 2003. Of these samples, 110 samples could not be collected due to the site being dry. Perchlorate was not detected in eight samples (66.7 percent) of the samples collected. Perchlorate concentrations in four of the samples collected (33.3 percent) ranged between the MDL (1 µg/L) and the RL (4 µg/L) and are flagged as estimated. No samples had perchlorate concentrations above the Reporting Limit (4 µg/L). During this storm event, the average perchlorate concentration at this site was 1.25 µg/L, and the maximum perchlorate concentration at this site was 3 µg/L. The perchlorate data table and plot for this station during this storm event are included in **Appendix G**.

Station Creek at 107 (SC3)
The project team collected a total of 93 samples as part of the storm sampling from May 2, 2003 to May 16, 2003. Perchlorate was not detected in 32 (34.4 percent) of the samples collected. Perchlorate concentrations in 29 of the samples collected (31.2 percent) ranged between the MDL (1 µg/L) and the RL (4 µg/L) and are flagged as estimated. A total of 32 samples had perchlorate concentrations between the RL(4 µg/L) and 11 µg/L. During this storm, the average perchlorate concentration at this site was 2.87 µg/L and the maximum perchlorate concentration was 11 µg/L. The perchlorate data table and plot for this station during this storm event are included in **Appendix F**.

The project team attempted to collect a total of 132 samples as part of the storm sampling from September 11, 2003 to October 2, 2003. Two of these samples could not be collected because the site was dry, and three samples could not be collected due to equipment error. Perchlorate was not detected in 127 samples (100 percent) of the samples collected during this storm. The perchlorate data table and plot for this station during this storm event are included in **Appendix G**.

Onion Creek at 107 (OC1)
The project team collected a total of 93 samples as part of the storm sampling from May 2, 2003 to May 16, 2003. Perchlorate was not detected in any of the 93 samples collected (100 percent). The perchlorate data table and plot for this station during this storm event are included in **Appendix F**.

The project team attempted to collect a total of 120 samples as part of the storm sampling from September 11, 2003 to October 2, 2003. Of these samples, 115 samples could not be collected because the site was dry. Perchlorate was not detected in 5 samples (100 percent) of the samples collected. The perchlorate data table and plot for this station during this storm event are included in **Appendix G**.

Station Creek at Oglesby Neff Park Road (SC5)
The project team attempted to collect a total of 84 samples as part of the storm sampling from May 2, 2003 to May 16, 2003. None of these samples could be collected because the site was dry. The perchlorate data table and plot for this station during this storm event are included in **Appendix F**.

The project team attempted to collect a total of 121 samples as part of the storm sampling from September 11, 2003 to October 2, 2003. None of these samples could be collected because the site was dry. The perchlorate data table and plot for this station during this storm event are included in **Appendix G**.

Leon River at 236 (LR1)
The project team collected a total of 90 samples as part of the storm sampling from May 2, 2003 to May 16, 2003. Perchlorate was not detected in 90 (100 percent) of the samples collected. The perchlorate data table and plot for this station during this storm event are included in **Appendix F**.

The project team attempted to collect a total of 132 samples as part of the storm sampling from September 11, 2003 to October 2, 2003. Of these samples, 28 samples could not be collected due to equipment error. Perchlorate was not detected in 104 samples (100 percent) of the samples collected. The perchlorate data table and plot for this station during this storm event are included in **Appendix G**.

5.1.1.2.3.2.2 NWIRP to Lake Waco

Harris Creek at Middle Windsor Road (HC1)
The project team collected a total of 95 samples as part of the storm sampling from May 2, 2003 to May 16, 2003. Perchlorate was not detected in 44 (46.3 percent) of the samples collected. Perchlorate concentrations in 51 of the samples collected (53.7 percent) ranged between the MDL (1 μg/L) and the RL (4 μg/L) and are flagged as estimated. No samples had perchlorate concentrations above the RL. During this storm, the average perchlorate concentration at this site was 0.96 μg/L and the maximum perchlorate concentration was 2 μg/L. The perchlorate data table and plot for this station during this storm event are included in **Appendix F**.

The project team attempted to collect a total of 128 samples as part of the storm sampling from September 11, 2003 to October 2, 2003. Of these samples, one sample could not be collected due to equipment error. Perchlorate was not detected in 125 (98.4 percent) of the samples collected. Perchlorate concentrations in two of the samples collected (1.6 percent) were at the MDL (1 μg/L) and are flagged as estimated. No samples had perchlorate concentrations above the RL. During this storm, the average perchlorate concentration at this site was 0.51 µg/L, and the maximum perchlorate concentration was 1 µg/L. The perchlorate data table and plot for this station during this storm event are included in **Appendix G**.

Harris Creek near Val Verde Road (HC2)
The project team collected a total of 98 samples as part of the storm sampling from May 2, 2003 to May 16, 2003. Perchlorate was not detected in 95 (96.9 percent) of the samples collected. Perchlorate concentrations in three of the samples collected (3.1 percent) were between the MDL (1 µg/L) and the RL (4 µg/L) and are flagged as estimated. No samples had perchlorate concentrations above the RL. During this storm, the average perchlorate concentration at this site was 0.54 µg/L, and the maximum perchlorate concentration was 2 µg/L. The perchlorate data table and plot for this station during this storm event are included in **Appendix F**.

The project team attempted to collect a total of 126 samples as part of the storm sampling from September 11, 2003 to October 2, 2003. Of these samples, one sample could not be collected because the site was dry, and three samples could not be collected due to equipment error. Perchlorate was not detected in 122 samples (100 percent) of the samples collected. The perchlorate data table and plot for this station during this storm event are included in **Appendix G**.

South Bosque River at Church Road (SBR3)
The project team attempted to collect a total of 90 samples as part of the storm sampling from May 2, 2003 to May 16, 2003. Of these samples, 52 samples could not be collected due to equipment errors resulting from high sedimentation on the strainer. Perchlorate was not detected in any of the 38 samples (100 percent) collected. The perchlorate data table and plot for this station during this storm event are included in **Appendix F**.

The project team attempted to collect a total of 112 samples as part of the storm sampling from September 11, 2003 to October 2, 2003. One of these samples could not be collected because the site was dry, and 41 samples could not be collected due to equipment errors resulting from high sedimentation on the strainer. One sample was broken in shipment. Perchlorate was not detected in any of the 69 samples (100 percent) collected and analyzed. The perchlorate data table and plot for this station during this storm event are included in **Appendix G**.

South Bosque River at Indian Trail (SBR1)
The project team collected a total of 92 samples as part of the storm sampling from May 2, 2003 to May 16, 2003. Perchlorate was not detected in 69 (75.0 percent) of the samples collected. Perchlorate concentrations in 22 of the samples collected (23.9 percent) ranged between the MDL (1 µg/L) and the RL (4 µg/L) and are flagged as estimated. One sample collected had a perchlorate concentration at the RL (4 µg/L). During this storm, the average perchlorate concentration at this site was 0.94 µg/L, and the maximum perchlorate concentration was 4 µg/L. The perchlorate data table and plot for this station during this storm event are included in **Appendix F**.

The project team attempted to collect a total of 125 samples as part of the storm sampling from September 11, 2003 to October 2, 2003. Of these samples, 47 samples could not be collected due to equipment error. Perchlorate was not detected in 57 (73.1 percent) of the samples collected. Perchlorate concentrations in 21 of the samples collected (26.9 percent) ranged between the MDL (1 µg/L) and the RL (4 µg/L) and are flagged as estimated. No samples had perchlorate concentrations above the RL. During this storm, the average perchlorate concentration at this site was 0.71 µg/L and the maximum perchlorate concentration was 2 µg/L. The perchlorate data table and plot for this station during this storm event are included in **Appendix G**.

South Bosque River near Cotton Belt Parkway (SBR2)
The project team collected a total of 102 samples as part of the storm sampling from May 2, 2003 to May 16, 2003. Perchlorate was not detected in 88 (86.3 percent) of the samples collected. Perchlorate concentrations in 14 of the samples collected (13.7 percent) ranged between the MDL (1 µg/L) and the RL (4 µg/L) and are flagged as estimated. No samples had perchlorate concentrations above the RL. The average perchlorate concentration at this site was 0.63 µg/L, and the maximum perchlorate concentration was 2 µg/L. The perchlorate data table and plot for this station during this storm event are included in **Appendix F**.

The project team attempted to collect a total of 133 samples as part of the storm sampling from September 11, 2003 to October 2, 2003. Of these samples, seven samples could not be collected because the site was dry, three samples could not be collected due to equipment error, and one sample bottle was broken in shipment. Perchlorate was not detected in any of the 122 samples collected (100 percent). The perchlorate data table and plot for this station during this storm event are included in **Appendix G**.

South Bosque River near Ruff Road (SBR4)
The project team collected a total of 94 samples as part of the storm sampling from May 2, 2003 to May 16, 2003. Perchlorate was not detected in 90 (95.7 percent) of the samples collected. Perchlorate concentrations in four of the samples collected (4.3 percent) were at the MDL (1 µg/L) and are flagged as estimated. No samples had perchlorate concentrations above the RL. The average perchlorate concentration at this site was 0.52 µg/L and the maximum perchlorate concentration was 1 µg/L. The perchlorate data table and plot for this station during this storm event are included in **Appendix F**.

The project team attempted to collect a total of 130 samples as part of the storm sampling from September 11, 2003 to October 2, 2003. Of these samples, one sample could not be collected because the site was dry, and one sample could not be collected due to equipment error. Perchlorate was not detected in any of the 128 samples (100 percent) collected. The perchlorate data table and plot for this station during this storm event are included in **Appendix G**.

South Bosque River at 84 (SBR5)
The project team collected a total of 93 samples as part of the storm sampling from May 2, 2003 to May 16, 2003. Perchlorate was not detected in 90 (96.8 percent) of the samples

collected. Perchlorate concentrations in 3 of the samples collected (3.2 percent) were between the MDL (1 μg/L) and the RL (4 μg/L) and are flagged as estimated. No samples had perchlorate concentrations above the RL. The average perchlorate concentration at this site was 0.53 μg/L, and the maximum perchlorate concentration was 2 μg/L. The perchlorate data table and plot for this station during this storm event are included in **Appendix F**.

The project team attempted to collect a total of 120 samples as part of the storm sampling from September 11, 2003 to October 2, 2003. Of these samples, 68 samples could not be collected because the site was dry, and seven samples could not be collected due to equipment error. Perchlorate was not detected in any of the 45 samples (100 percent) collected. The perchlorate data table and plot for this station during this storm event are included in **Appendix G**.

Middle Bosque River (MBR1)

The project team collected a total of 88 samples as part of the storm sampling from May 2, 2003 to May 16, 2003. Perchlorate was not detected in any of the 88 samples (100 percent) collected. The perchlorate data table and plot for this station during this storm event are included in **Appendix F**.

The project team attempted to collect a total of 101 samples as part of the storm sampling from September 11, 2003 to October 2, 2003. Six of these samples could not be collected due to equipment error. Perchlorate was not detected in any of the 95 samples (100 percent) collected. The perchlorate data table and plot for this station during this storm event are included in **Appendix G**.

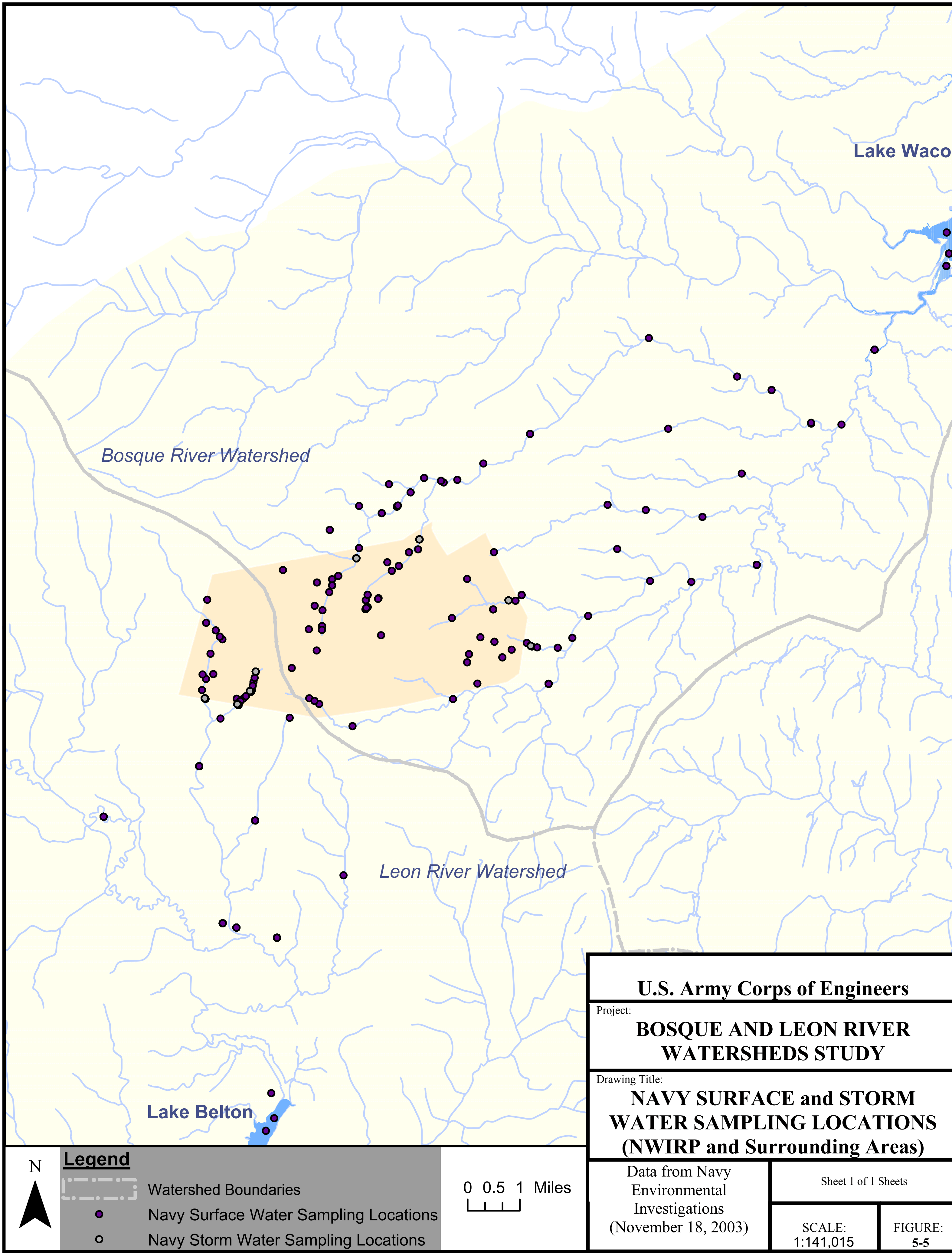
5.1.1.2.3.2.3 Cowhouse Creek at Tank Destroyer Road (CHC1)

The project team collected a total of 95 samples as part of the storm sampling from May 2, 2003 to May 16, 2003. Perchlorate was not detected in any of the 95 samples collected (100 percent). The perchlorate data table and plot for this station during this storm event are included in **Appendix F**.

The project team attempted to collect a total of 132 samples as part of the storm sampling from September 11, 2003 to October 2, 2003. Two of these samples could not be collected due to equipment error. Perchlorate was not detected in any of the 130 samples collected (100 percent). The perchlorate data table and plot for this station during this storm event are included in **Appendix G**.

5.1.1.2.4 Historical Data

The U.S. Navy conducted surface water sampling for perchlorate between 1998 and 2003 and storm water sampling at the perimeter of NWIRP McGregor in 2000 and 2001. The locations of the surface water and storm water sampling points are shown in **Figure 5-5**. All locations that had a detection greater than 4 μg/L at any time are shown on **Figure 5-6**. Detailed results of all sampling conducted by the Navy are presented in the *Draft-Final Groundwater Investigation Phase III Report* (EnSafe, 2003). A summary of the historical perchlorate analytical results from this report is presented below.



U.S. Army Corps of Engineers

Project:
BOSQUE AND LEON RIVER WATERSHEDS STUDY

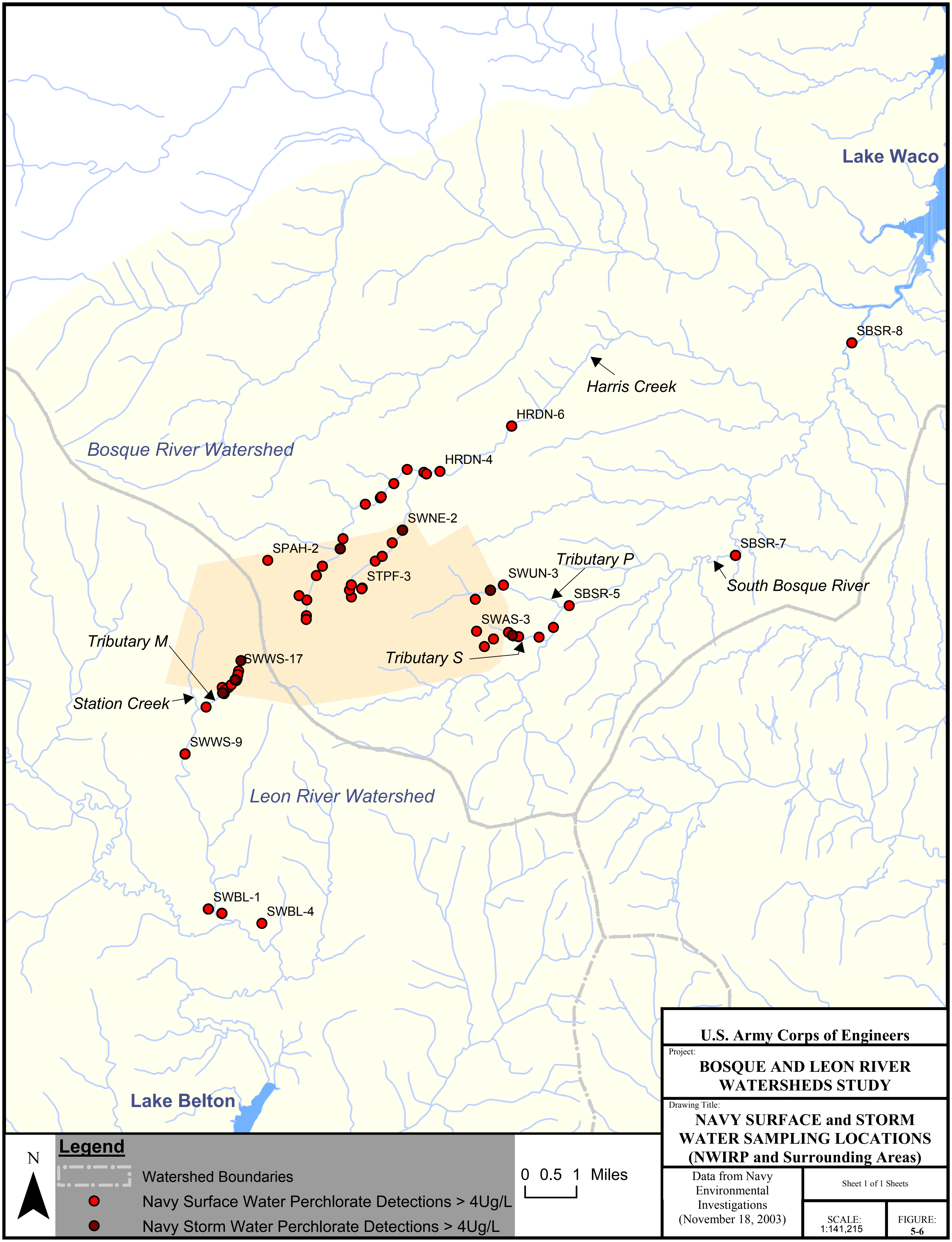
Drawing Title:
NAVY SURFACE and STORM WATER SAMPLING LOCATIONS (NWIRP and Surrounding Areas)

Data from Navy Environmental Investigations (November 18, 2003)

Sheet 1 of 1 Sheets

SCALE: 1:141,015

FIGURE: 5-5



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Project:

BOSQUE AND LEON RIVER WATERSHEDS STUDY

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NAVY SURFACE and STORM WATER SAMPLING LOCATIONS (NWIRP and Surrounding Areas)

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SCALE: 1:141,215

FIGURE: 5-6

5.1.1.2.4.1 NWIRP To Lake Belton

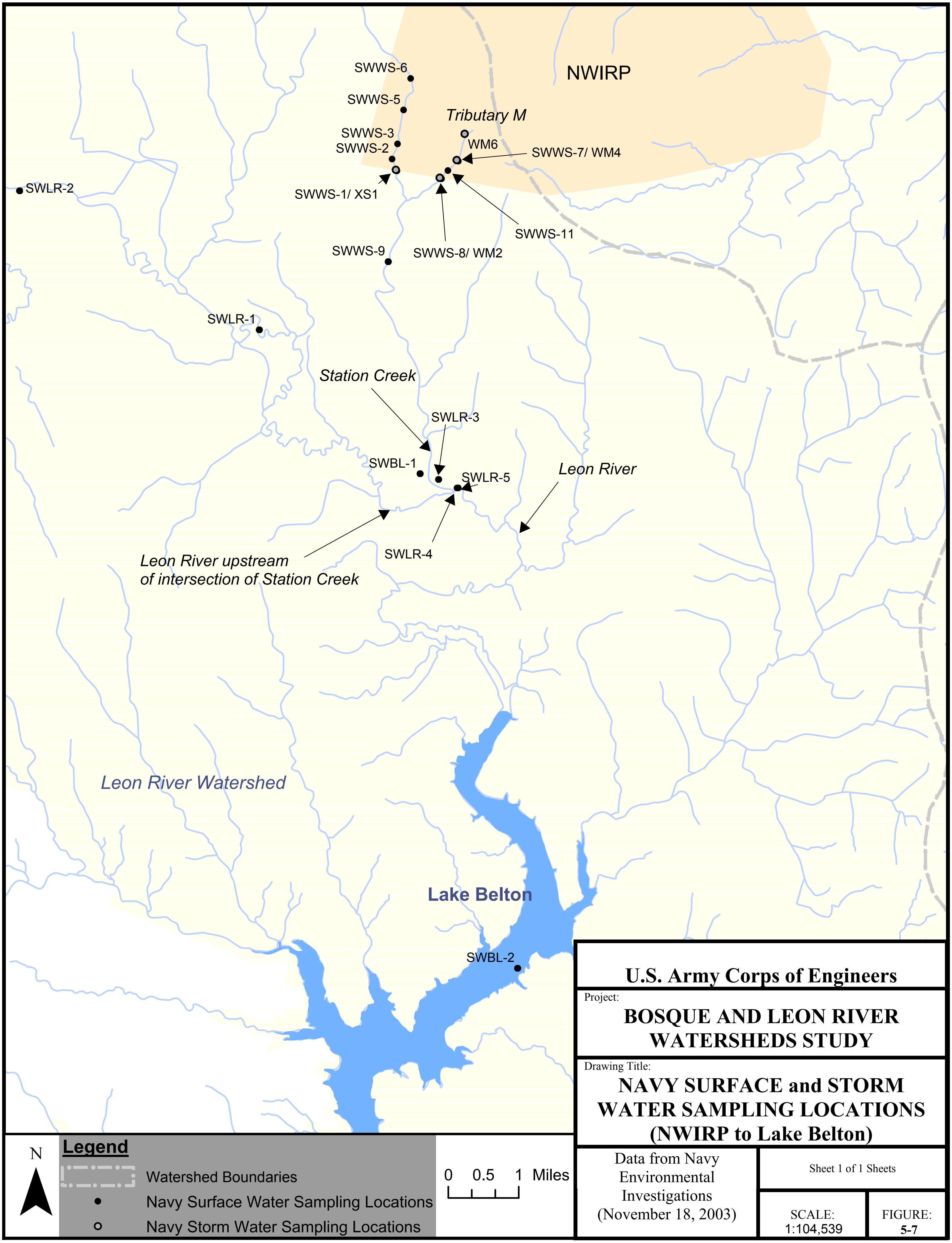
This section discusses the history of U.S. Navy perchlorate sampling conducted from NWIRP to Lake Belton. The locations where perchlorate was detected are discussed further below and are shown in **Figure 5-7**.

Station Creek Upstream of Intersection of Tributary M

In 1998, the surface water quality of Station Creek was initially evaluated by collecting five grab samples (SWWS-2, SWWS-3, SGAM-1 (*not in map*), SWWS-5 and SWWS-6) which were all non-detect for perchlorate. Eighteen additional surface water samples were collected from Station Creek (SWWS-1) upstream of the intersection of Tributary M between January 8, 1999 and September 1, 2002 and analyzed for perchlorate. Of these samples, two samples had perchlorate detections of 3.8 J µg/L (March 2000) and 12 µg/L (October 2001). Storm water samples were collected from March to June 2000. Ten rain events were recorded, and 40 grab and composite samples were collected from this stream section. All were non-detect for perchlorate except for one composite sample which had a detection of 3.8 J µg/L. Storm sampling was also conducted in November 2000, and January, May, and September 2001 at XS1 (Station Creek and the NWIRP South Property line). All the samples collected were non-detect for perchlorate during each event.

Tributary M

Surface water in Tributary M has been closely monitored since January 1999 to evaluate the effectiveness of the Interim Stabilization Measures (ISM) system. This system was installed in 1999 along the southern boundary of NWIRP near Tributary M to capture contaminated groundwater before it flows offsite. SWWS-8 is a monthly sampling location where Tributary M exits the property. From January to June 1999, samples were analyzed for perchlorate at this location. Before the ISM was in place, perchlorate was detected four times in SWWS-8 samples: 5,500 µg/L (1/11/99), 3,600 µg/L (4/19/99), 4,700 µg/L (5/11/99), and 3,100 µg/L (7/16/99). Surface water samples were then collected along Tributary M at various time intervals and distances to better define perchlorate contamination in surface water and groundwater so that an interim response action plan could be implemented. In January 1999, SWWS-7 was collected at Tributary M at the perimeter road and was analyzed for perchlorate. Perchlorate was detected at 2,300 µg/L. In February 1999, SWWS-11 was collected 800 feet north of SWWS-8 and analyzed for perchlorate. Perchlorate was detected at 1,800 µg/L. Eight surface water samples were collected on April 19, 1999 at different locations along Tributary M and analyzed for perchlorate. Based on this information and corresponding data, the U.S. Navy established that the groundwater-to-surface water pathway was the main mechanism for contaminant transfer along the southern boundary at NWIRP. As a result, in late summer and early fall of 1999, ISM trenches were put in place to intercept the groundwater-to-surface water pathway and to abate the offsite migration of perchlorate and other contaminants. The trenches were designed to capture, collect and treat groundwater that would normally be discharged to Tributary M under natural processes. These trenches were slightly modified to support an in-situ pilot test as in-situ permeable reactive barriers (PRBs) were shown to viable alternatives to pump-and-treat.



U.S. Army Corps of Engineers

Project:

BOSQUE AND LEON RIVER WATERSHEDS STUDY

Drawing Title:

NAVY SURFACE and STORM WATER SAMPLING LOCATIONS (NWIRP to Lake Belton)

Data from Navy Environmental Investigations (November 18, 2003)

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SCALE: 1:104,539

FIGURE: 5-7

Initial results showed perchlorate could be reduced to non-detect levels in the PRB's. However, aquifer water levels rose in March 2000, and a seep developed at the intersection of the property line trench and Tributary M. Eighty-one samples were collected from the seep from March 6, 2000 and July 24, 2000, when the seep flow ceased. Fifty-six (56) samples were non-detect for perchlorate and the remaining 25 samples ranged from 5.2 µg/L to 4,200 µg/L. From July to September 2000, additional water storage capacity (8 million gallons) was constructed to help store additional water and control the seep during the next wet season. However, beginning in late October 2000, heavy rains began (200% above normal) and continued into November overwhelming the available storage capacity. Additional rainfall in late December caused the water level in the trench to intersect the Tributary M streambed and another seep began to flow. From January 5 to May 9, 2001, 123 grab samples were collected from the seep. Perchlorate was detected in all except two samples and ranged from non-detect to 5,300 µg/L and average 2,200 µg/L. Because water levels in the trench system have been pumped down since May 2001 to control the aquifer water level, Tributary M remains dry for most of the year, except during storm events. Four samples have been collected since May 2001 and perchlorate concentrations range from 4.1 µg/L (4/10/2002) to 480 µg/L (1/8/2002). Storm sampling was also conducted in 2000 at various points along Tributary M to access possible soil-surface water cross media contamination (WM2, WM4, WM6). WM2 recorded seven storm events and collected twenty-three grab samples which ranged from non-detect to 500 µg/L. WM4 recorded four storm events and collected 12 grab samples which ranged from non-detect to 26 µg/L. WM6 recorded two storm events and collected eight grab samples which were non-detect for perchlorate. Tributary M flows into a stock pond in the Texas A&M property after leaving the NWIRP plant. This stock pond was sampled three times and analyzed for perchlorate in March 2000 (7.3 µg/L), September 2000 (non-detect) and December 2000 (370 µg/L).

Station Creek Downstream of Intersection of Tributary M

An in-situ pilot system is installed downstream of the intersection of Station Creek and Tributary M. It begins at the Texas A&M south property line and extends 1,700 feet to the northeast. The system and pilot study results are presented in detail in the *Offsite In Situ Bioremediation (Bio-Borings) Pilot Study Report* (EnSafe, 2002).

Samples were collected from SWWS-9 (Station Creek at 107) whenever the stream was flowing from September 18, 1998 to September 1, 2002. Thirty-one (31) samples were collected which ranged from non-detect to 540 µg/L and averaged 88.5 µg/L. Before May 2001, when an emergency discharge order was in effect, the average perchlorate concentration was 144.5 µg/L with two non-detect values recorded at this time. The U.S. Navy findings indicate that between May 2001 and September 2002 the average concentration dropped to 20.4 µg/L (an 86% reduction).

Samples were collected from SWBL-1 (Station Creek under Park Road) between February 1999 and September 1, 2002. Results ranged from non-detect (4 µg/L) to 210 µg/L and averaged 36 µg/L. The average pre-May 2001 concentration was 59 µg/L. The U.S. Navy findings indicate that between May 2001 and September 2002 the average concentration dropped to 11 µg/L (an 82% reduction).

Leon River upstream of Intersection of Station Creek
Samples were collected upstream of the confluence of Station Creek and Leon River at SWLR-1 (Leon River at County Road 344 (3.4 miles upstream)) and SWLR-2 (Leon River at County Road 315 (6.5 miles upstream)) from July 1999 to September 1, 2002. Thirty-six samples were collected from each station and all were non-detect for perchlorate.

Leon River downstream of Intersection of Station Creek
Samples were also collected at different points downstream of the confluence of Station Creek and the Leon River to understand the mixing dynamics of the two bodies.

Twenty samples were collected from SWLR-3 (150 feet downstream) and ranged from non-detect (< 2 µg/L) to 27 µg/L. Nine of these samples were non-detect for perchlorate. The U.S. Navy found the perchlorate concentration at this location comparable to concentrations at Station Creek and Park Road (SWBL-1). Based on these results and a detailed flow and mixing analysis, the U.S. Navy concluded that SWBL-1 was considered to lie in a backwater area of Station Creek in the Leon River, and thus, not representative of Leon River water quality.

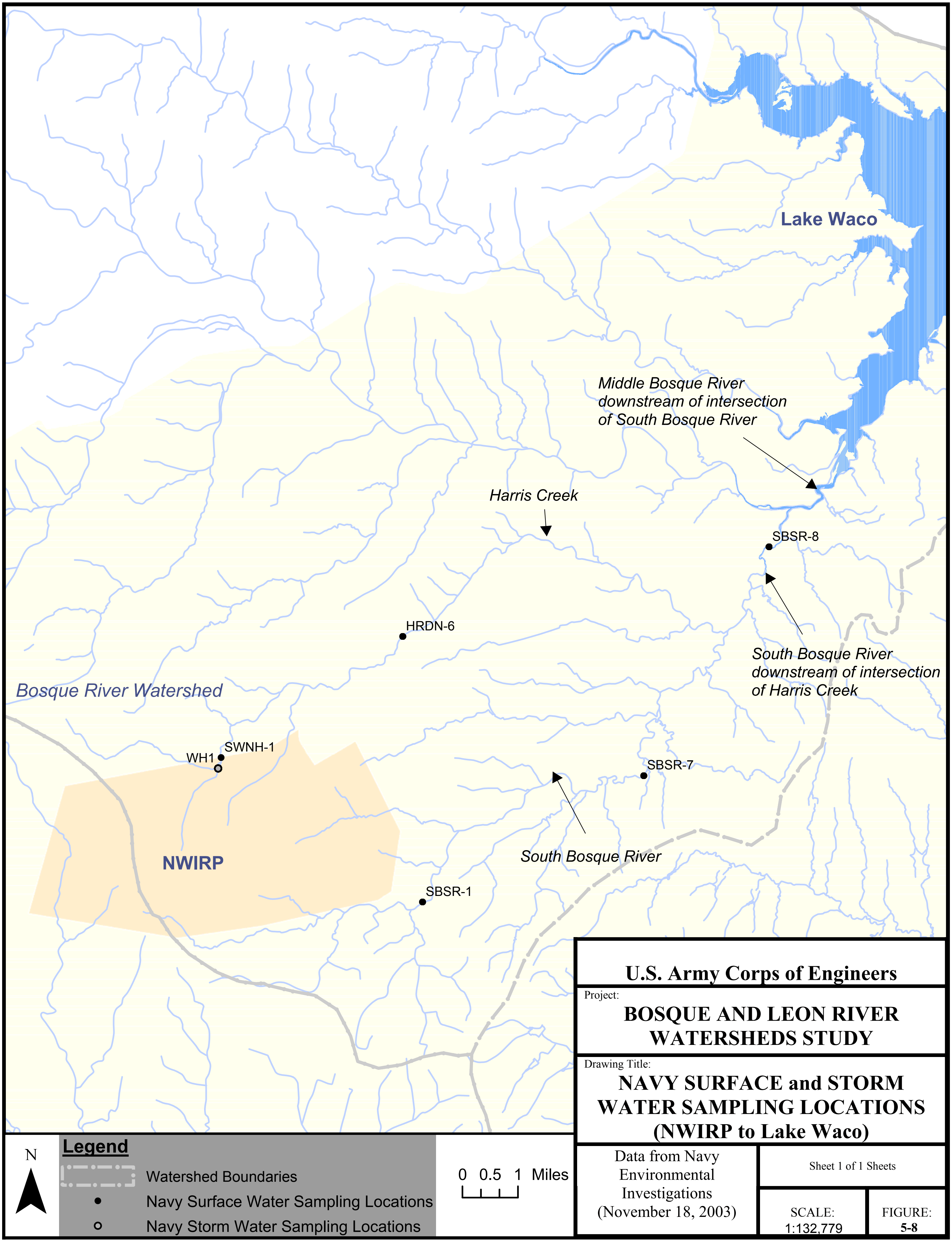
Six surface water samples were collected from two additional locations downstream of the confluence from SWLR-4 (250 feet downstream) and SWLR-5 (350 feet downstream), respectively from March 2002 to September 1, 2002. All samples collected from SWLR-4 and SWLR-5 were non-detect for perchlorate. The U.S. Navy has determined that perchlorate results from these locations are representative of the Leon River water quality.

Forty-two surface water samples were collected from SWBL-2 (Leon River at Highway 236). This location is upstream of where the Leon River enters Lake Belton and is 3,600 feet downstream of the confluence of Station Creek and the Leon River. Perchlorate results were non-detect except for April 8, 1999 when it was detected at 2.6 µg/L.

5.1.1.2.4.2 NWIRP to Lake Waco

This section discusses the history of the U.S. Navy sampling conducted from NWIRP to Lake Waco. The locations where perchlorate was detected are discussed further below in **Figure 5-8**.

Harris Creek
Twenty-one surface water samples were collected from Harris Creek at SWNH-1 between January 10, 1999 and September 1, 2002. Perchlorate concentrations ranged from non-detect to 1,600 µg/L. The 1,600 µg/L sample was collected on April 10, 2002, but the perchlorate concentration at the same location collected a week later was 7.1 µg/L. Excluding the 1,600 µg/L sample, perchlorate concentrations ranged from 1 µg/L to 15 µg/L in 12 samples with an average of 11.3 µg/L. Perchlorate was not detected in the remaining nine samples. Storm water samples were collected from March to June 2000. WH1 recorded five rain events and collected 17 grab samples. 11 were non-detect



U.S. Army Corps of Engineers

Project:

BOSQUE AND LEON RIVER WATERSHEDS STUDY

Drawing Title:

NAVY SURFACE and STORM WATER SAMPLING LOCATIONS (NWIRP to Lake Waco)

Data from Navy Environmental Investigations (November 18, 2003)

Sheet 1 of 1 Sheets

SCALE: 1:132,779

FIGURE: 5-8

for perchlorate and six had concentrations ranging from 3.3 J µg/L to 24 µg/L. Monthly surface water samples were collected at HRDN-6 (Harris Creek and Windsor Road) when Harris Creek was flowing. Thirty-nine samples were collected from February 1999 to September 2002. Perchlorate was detected in 12 samples with concentrations ranging from 3.2 µg/L to 9.6 µg/L with an average of 5.2 µg/L.

South Bosque River

Monthly surface water samples have been collected from three locations along the South Bosque River since 1999. These are SBSR-1 (South Bosque River at Highway 317 and upstream of the confluence of Tributary S and Tributary P with the South Bosque River), SBSR-7 (South Bosque River at Cotton Belt Parkway and downstream of the confluence) and SBSR-8 (South Bosque Road at Old Lorena Road and downstream of the confluence).

Thirty monthly surface water samples were collected at SBSR-1 from July 1998 to September 1, 2002 when the stream was flowing. Perchlorate was detected at 0.45 µg/L in one of the samples collected. Thirty-six surface water samples were collected at SBSR-7 from February 1999 to September 1, 2002 when the river was flowing. Perchlorate was detected in 17 samples at an average of 6 µg/L and ranged from 4 µg/L to 9.9 µg/L. Thirty-nine surface water samples were collected further downstream at SBSR-8 from February 1999 to September 1, 2002 when the river was flowing. Perchlorate was detected in 10 samples at an average of 4.5 µg/L and ranged from 1.2 µg/L to 13 µg/L.

Based on the results of the stream monitoring program and the lake studies described in Section 5.1.2.4, the U.S. Navy concluded that perchlorate concentrations have, in general decreased from 1999. Perchlorate concentrations in surface water decreases away from the facility and is not present above the drinking water standard in area drinking water reservoirs. The U.S. Navy attributed the general decrease in perchlorate concentration reduction to various factors including absence of continued source loading (the facility ceased operation in 1996), ongoing introduction of clean water through precipitation, and the result of interim remedial actions completed to mitigate offsite migration of perchlorate in groundwater and surface water along the impacted tributaries; Tributary M (Fall 1999) and Tributary S (October 2002). The U.S. Navy also plans further remedial actions for the offsite property south of Area M in early summer of 2004.

5.1.1.2.5 Discussion

As in previous sections, the stream network has been divided into two stream segment study areas (NWIRP to Lake Belton and NWIRP to Lake Waco) and data are discussed moving from upstream to downstream in the following sections. An additional tributary to Lake Belton, Cowhouse Creek, was also evaluated during this study to determine if runoff from Fort Hood might be contributing detectable concentrations of perchlorate to Lake Belton. The following discussion summarizes all of the biweekly perchlorate data gathered for surface water as a part of this project. Average perchlorate concentrations reported here for each station are based on the bi-weekly samples.

5.1.1.2.5.1 NWIRP to Lake Belton

This section summarizes findings from perchlorate sampling in streams along the various surface drainage routes to Lake Belton collected during this study.

Tributary M - Station Creek - Leon River (TRM1, SC3, SC5, LR1)

Tributary M to Station Creek to the Leon River is one potential route for perchlorate contamination from NWIRP runoff to reach the Leon River and Lake Belton. As shown on **Figure 5-9**, perchlorate concentrations in Tributary M at TRM1 are at a maximum of 111 µg/L and at an average of 10.1 µg/L. This decreases to a maximum perchlorate concentration of 38 µg/L and an average perchlorate concentration of 5.11 µg/L in Station Creek at SC3 beyond the intersection of Tributary M and Station Creek. This further decreases to a maximum perchlorate concentration of 7.6 µg/L and an average perchlorate concentration of 2.73 µg/L in Station Creek at SC5 beyond the intersection of Station Creek and Onion Creek. Finally, there are no perchlorate detections in the Leon River at LR1 beyond its intersection with Station Creek.

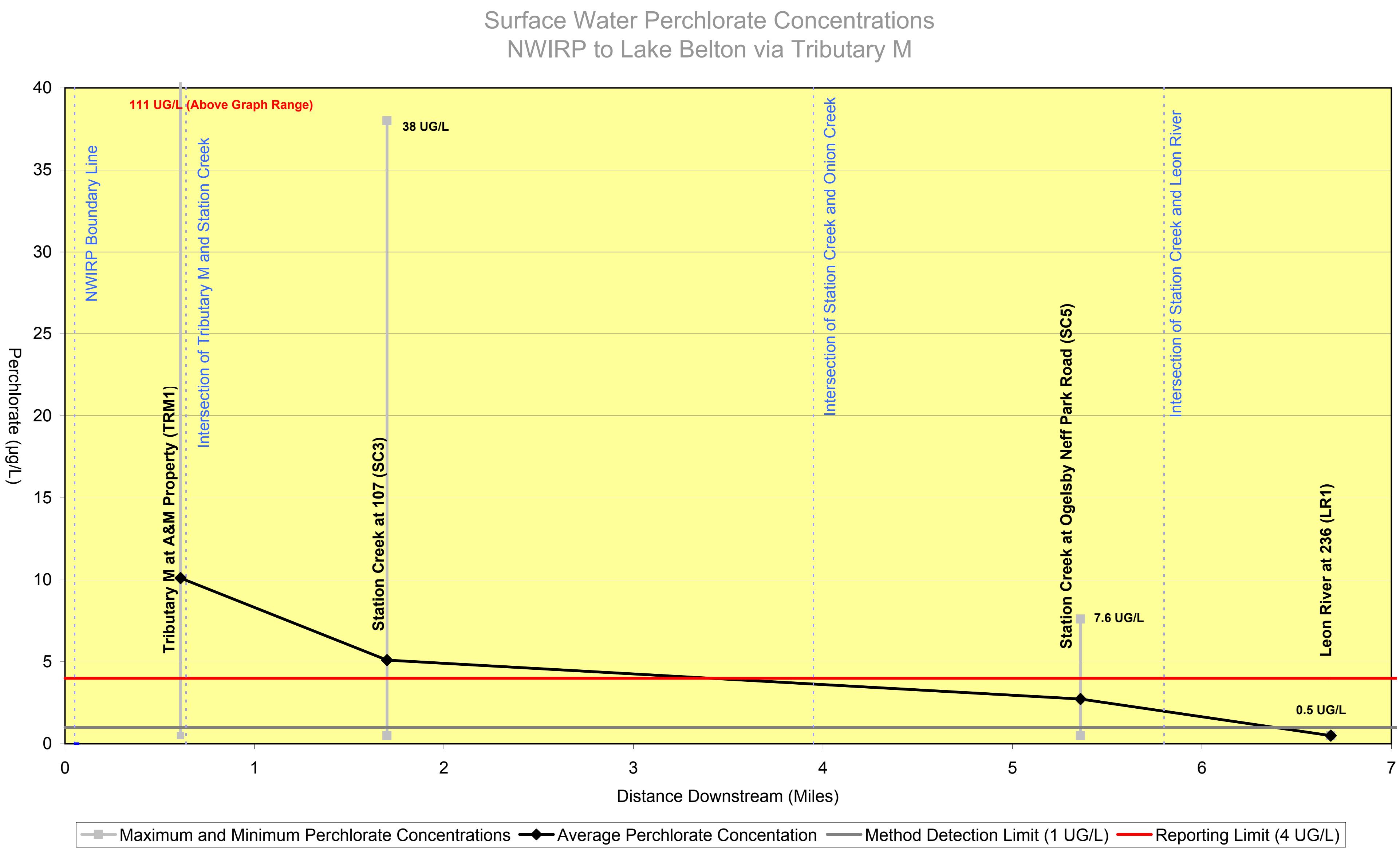
Station Creek - Leon River (SC1, SC3, SC5, LR1)

Station Creek to the Leon River is a second potential route for perchlorate from NWIRP to reach Lake Belton via surface flow. As shown on **Figure 5-10**, there have been no perchlorate concentrations detected in Station Creek at monitoring station SC1. Since perchlorate concentration increases to a maximum of 38 µg/L and an average of 5.11 µg/L in Station Creek at SC3 beyond the intersection of Tributary M and Station Creek, Station Creek (SC1) is likely not a significant contributor of perchlorate to Station Creek (SC3). The perchlorate in Station Creek at SC3 is likely originating from Tributary M (TRM1).

Onion Creek - Station Creek - Leon River (OC1, SC3, SC5, LR1)

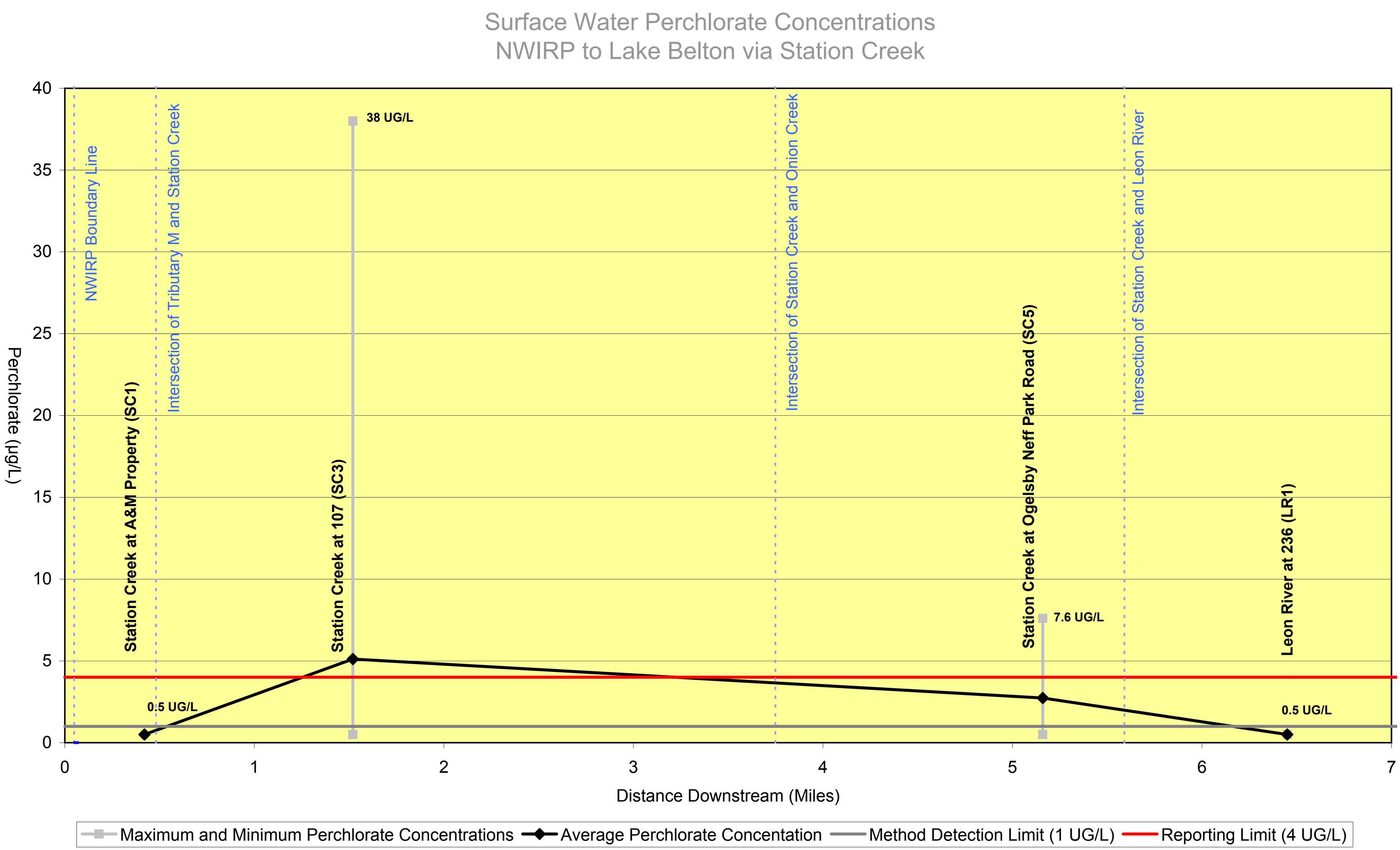
Onion Creek is the third route that surface runoff from NWIRP may follow to Lake Belton. As shown on **Figure 5-11**, perchlorate concentrations in Onion Creek at OC1 are at a maximum of 3 µg/L and at an average of 0.56 µg/L. Onion Creek (OC1) has only had one perchlorate detection in all the perchlorate sampling conducted as part of this project. This detection occurred in a duplicate sample and perchlorate was not detected in the original sample. Since perchlorate concentration increases to a maximum of 7.6 µg/L and an average of 2.73 µg/L in Station Creek at SC5 beyond the intersection of Onion Creek and Station Creek, Onion Creek (OC1) is not likely to be a significant contributor of perchlorate to Station Creek (SC5). The perchlorate is more likely migrating from Station Creek (SC3).

Figure 5-9



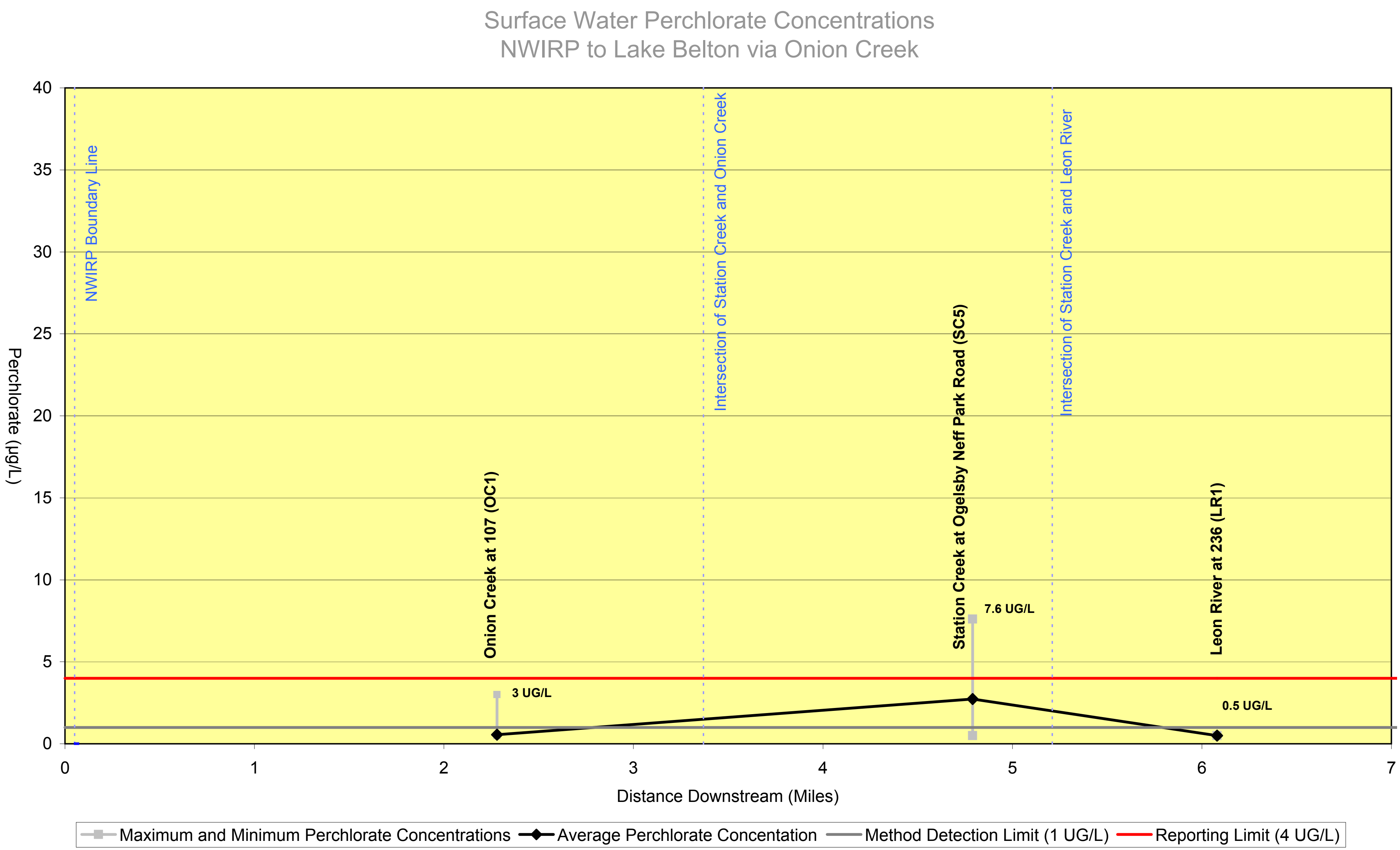
Surface Water Perchlorate Concentrations
NWIRP to Lake Belton via Tributary M
Perchlorate (µg/L)
Distance Downstream (Miles)
0
5
10
15
20
25
30
35
40
0
1
2
3
4
5
6
7
111 UG/L (Above Graph Range)
38 UG/L
7.6 UG/L
0.5 UG/L
NWIRP Boundary Line
Intersection of Tributary M and Station Creek
Intersection of Station Creek and Onion Creek
Intersection of Station Creek and Leon River
Tributary M at A&M Property (TRM1)
Station Creek at 107 (SC3)
Station Creek at Ogelsby Neff Park Road (SC5)
Leon River at 236 (LR1)
Maximum and Minimum Perchlorate Concentrations
Average Perchlorate Concentation
Method Detection Limit (1 UG/L)
Reporting Limit (4 UG/L)

Figure 5-10



Surface Water Perchlorate Concentrations
NWIRP to Lake Belton via Station Creek
Perchlorate (µg/L)
Distance Downstream (Miles)
NWIRP Boundary Line
Intersection of Tributary M and Station Creek
Intersection of Station Creek and Onion Creek
Intersection of Station Creek and Leon River
Station Creek at A&M Property (SC1)
Station Creek at 107 (SC3)
Station Creek at Ogelsby Neff Park Road (SC5)
Leon River at 236 (LR1)
38 UG/L
7.6 UG/L
0.5 UG/L
0.5 UG/L
Maximum and Minimum Perchlorate Concentrations
Average Perchlorate Concentation
Method Detection Limit (1 UG/L)
Reporting Limit (4 UG/L)

Figure 5-11



Surface Water Perchlorate Concentrations
NWIRP to Lake Belton via Onion Creek
Perchlorate (µg/L)
40
35
30
25
20
15
10
5
0
0
1
2
3
4
5
6
7
Distance Downstream (Miles)
NWIRP Boundary Line
Intersection of Station Creek and Onion Creek
Intersection of Station Creek and Leon River
Onion Creek at 107 (OC1)
Station Creek at Ogelsby Neff Park Road (SC5)
Leon River at 236 (LR1)
3 UG/L
7.6 UG/L
0.5 UG/L
Maximum and Minimum Perchlorate Concentrations
Average Perchlorate Concentation
Method Detection Limit (1 UG/L)
Reporting Limit (4 UG/L)

5.1.1.2.5.2 NWIRP to Lake Waco

This section summarizes findings from perchlorate sampling in streams along the various surface drainage routes to Lake Waco.

Harris Creek - South Bosque River - Middle Bosque River (HC1, HC2, SBR3, SBR5, MBR1)

Harris Creek to the South Bosque River to the Middle Bosque River is one potential route for perchlorate from NWIRP to reach Lake Waco via surface flow. As shown on **Figure 5-12**, perchlorate concentrations in Harris Creek at HC1 are at a maximum of 6.5 μg/L and at an average of 1.81 μg/L. This decreases to a maximum perchlorate concentration of 4.8 μg/L and an average perchlorate concentration of 1.25 μg/L in Harris Creek (HC2) and then to a maximum perchlorate concentration of 2 μg/L and an average perchlorate concentration of 0.88 μg/L in the South Bosque River (SBR3). This remains consistent with a maximum perchlorate concentration of 2 μg/L and an average perchlorate concentration of 0.81 μg/L in South Bosque River (SBR5) beyond the intersection of Harris Creek and South Bosque River. Finally, there are no perchlorate detections in the Middle Bosque River at MBR1 beyond its intersection with the South Bosque River.

South Bosque River - Middle Bosque River (SBR1, SBR2, SBR4, SBR5, MBR1)

The South Bosque River to the Middle Bosque River is a second route that surface runoff from NWIRP could follow to Lake Waco. As shown on **Figure 5-13**, perchlorate concentrations in the South Bosque River at SBR1 reach a maximum of 4.7 μg/L and average 2.73 μg/L. This concentration decreases to a maximum perchlorate concentration of 3 μg/L and an average perchlorate concentration of 1.51 μg/L in the South Bosque River (SBR2). The maximum perchlorate concentration detected further downstream in the South Bosque River (SBR4) is 3 μg/L, and the average perchlorate concentration is 1.10 μg/L. This concentration further decreases to a maximum of 2 μg/L and an average of 0.81 μg/L in South Bosque River (SBR5) beyond the intersection of Harris Creek and South Bosque River. Finally, there are no perchlorate detections in the Middle Bosque River at MBR1 beyond the intersection of South Bosque River and the Middle Bosque River.

5.1.1.2.5.3 Cowhouse Creek at Tank Destroyer Road (CHC1)

We found no evidence of perchlorate contributions to Lake Belton from the Fort Hood drainage of Cowhouse Creek, as no perchlorate was detected at monitoring station CHC1 during this project.

Figure 5-12

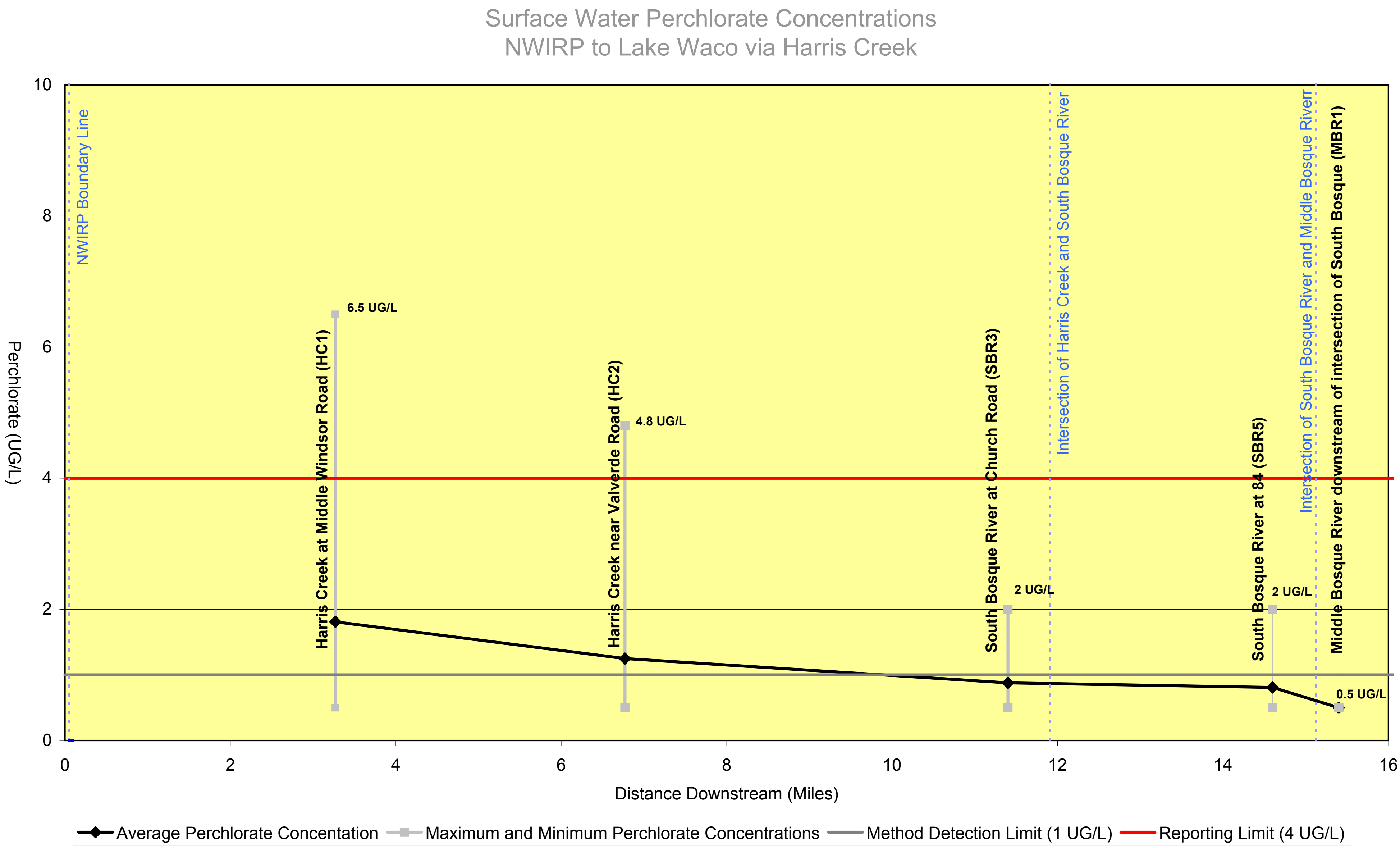
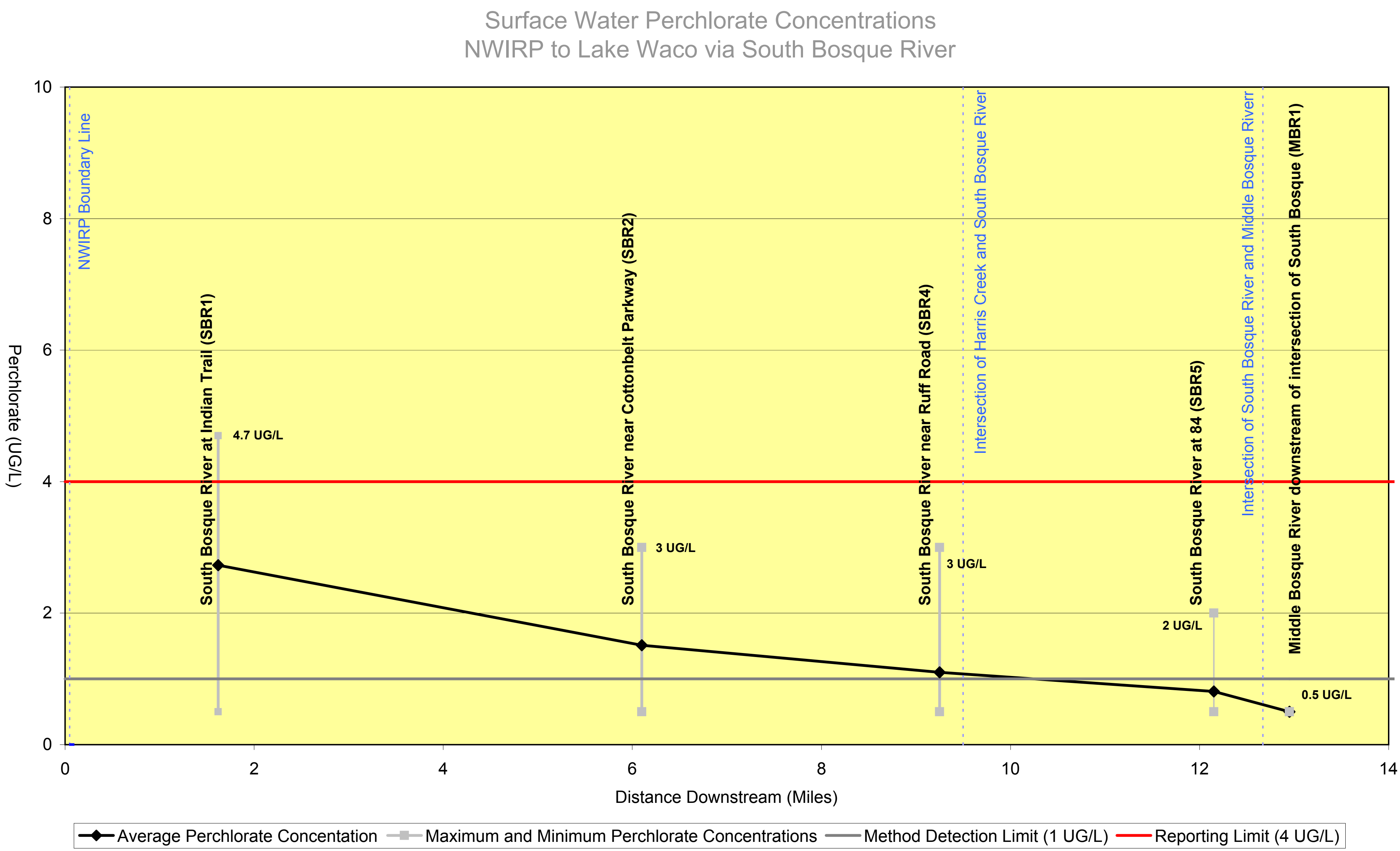

Surface Water Perchlorate Concentrations
NWIRP to Lake Waco via Harris Creek
Perchlorate (UG/L)
Distance Downstream (Miles)
NWIRP Boundary Line
Harris Creek at Middle Windsor Road (HC1)
6.5 UG/L
Harris Creek near Valverde Road (HC2)
4.8 UG/L
South Bosque River at Church Road (SBR3)
2 UG/L
Intersection of Harris Creek and South Bosque River
South Bosque River at 84 (SBR5)
2 UG/L
Intersection of South Bosque River and Middle Bosque Riverr
Middle Bosque River downstream of intersection of South Bosque (MBR1)
0.5 UG/L
0
2
4
6
8
10
0
2
4
6
8
10
12
14
16
Average Perchlorate Concentation
Maximum and Minimum Perchlorate Concentrations
Method Detection Limit (1 UG/L)
Reporting Limit (4 UG/L)

Figure 5-13



Surface Water Perchlorate Concentrations
NWIRP to Lake Waco via South Bosque River
Perchlorate (UG/L)
Distance Downstream (Miles)
0
2
4
6
8
10
12
14
NWIRP Boundary Line
South Bosque River at Indian Trail (SBR1)
4.7 UG/L
South Bosque River near Cottonbelt Parkway (SBR2)
3 UG/L
South Bosque River near Ruff Road (SBR4)
3 UG/L
Intersection of Harris Creek and South Bosque River
South Bosque River at 84 (SBR5)
2 UG/L
Intersection of South Bosque River and Middle Bosque Riverr
Middle Bosque River downstream of intersection of South Bosque (MBR1)
0.5 UG/L
Average Perchlorate Concentation
Maximum and Minimum Perchlorate Concentrations
Method Detection Limit (1 UG/L)
Reporting Limit (4 UG/L)

5.1.1.2.5.4 Overall Evaluation

Based on the historical data presented and the bi-weekly and storm sampling data collected during this study, the following observations have been made regarding perchlorate in streams.

(1) Perchlorate has been detected consistently in the South Bosque, Harris Creek and Station Creek streams since 1998. However, concentrations have decreased significantly over time in each of these locations as follows:

- Concentrations in Tributary M ranged from a minimum of 3,100 µg/L to a maximum of 5,500 in the upper stream reaches (Tributary M where it crosses the NWIRP boundary) based on the data collected by the U.S. Navy from January 1999 to July 1999. Perchlorate concentrations were found to be much lower during this study in Tributary M just south of the NWIRP boundary (TRM1) and ranged from non-detect (< 1 µg/L) to 111 µg/L. These decreases in perchlorate concentrations appear to be the result of significant source removal, groundwater collection, and groundwater remediation efforts at NWIRP by the U.S. Navy. These remedial activities have significantly reduced the quantities and concentrations of impacted groundwater leaving this site and entering adjoining streams.
- Concentrations in Station Creek at 107 (SWWS-9) ranged from a minimum of non-detect to a maximum of 540 µg/L based on the data collected by the U.S. Navy from September 1998 to September 2002. Perchlorate concentrations were found to be much lower during this study in Station Creek at 107 (SC3) and ranged from non-detect (< 1 µg/L) to 38 µg/L.
- Concentrations in Harris Creek ranged from a minimum of 3.2 µg/L to a maximum of 9.6 µg/L based on the data collected by the U.S. Navy at HRDN-6 from February 1999 to September 2002. Perchlorate concentrations were found to be lower during this study in Harris Creek (HC1) and ranged from non-detect (<1 µg/L) to 6.5 µg/L.
- Concentrations in the South Bosque River upper reaches (SBSR-7) ranged from a minimum of 4 µg/L to a maximum of 9.9 µg/L based on the data collected by the U.S. Navy from February 1999 to September 1, 2002. Perchlorate concentrations were found to be lower during this study in the South Bosque River upper reaches (SBR2) and ranged from non-detect (<1 µg/L) to 3 µg/L. Concentrations in the South Bosque River lower reaches (SBSR-8) ranged from a minimum of 1.2 µg/L to a maximum of 13 µg/L based on the data collected by the U.S. Navy from February 1999 to September 1, 2002. Perchlorate concentrations were found to be lower during this study in the South Bosque River lower reaches (SBR5) and ranged from non-detect (<1 µg/L) to 2 µg/L.

(2) Perchlorate concentrations decrease the further you move downstream from the NWIRP property. Dilution is the likely cause of these decreased concentrations.

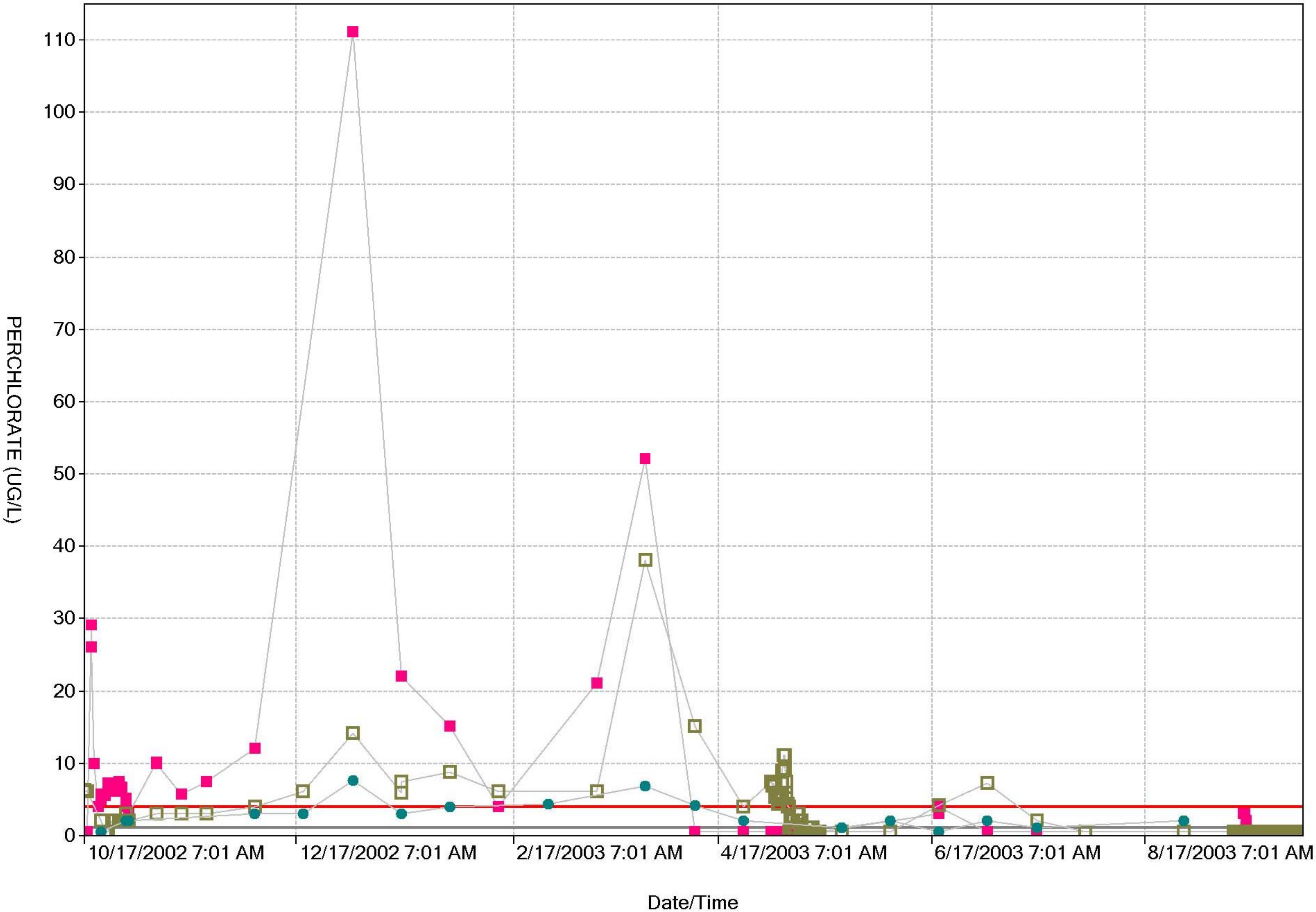
(3) All samples collected from stations SC1, OC1, SBR2, SBR3, SBR4, and SBR5 during all bi-weekly and storm sampling events have been below the interim action level for perchlorate (4 μg/L).

(4) All samples collected from the major rivers during bi-weekly and storm sampling events, including Cowhouse Creek (262 samples), the Middle Bosque River (218 samples) and the Leon River (230 samples) have all been below detectable levels (<1 μg/L) for perchlorate.

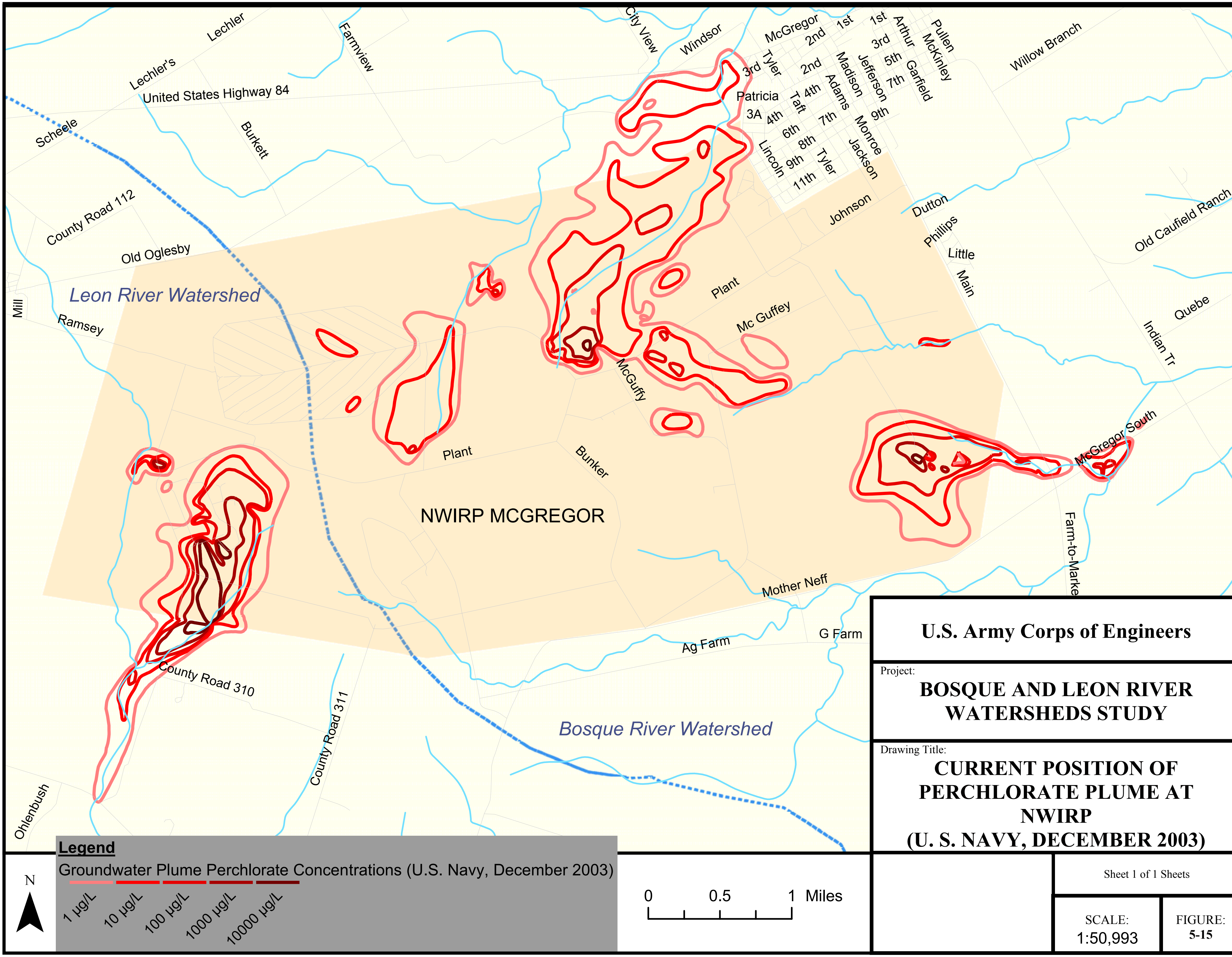
(5) Detected concentrations are still subject to spikes that may occur as shown on **Figure 5-14**.

(6) In addition to all the surface water sampling discussed above, many groundwater sample locations have been sampled multiple times by the U.S. Navy since the Groundwater Investigation began in 1998. The current position of the plume is shown in **Figure 5-15**. The plume size has been decreasing at a rate of 5 to 7% per year, according to the U.S. Navy.

Figure 5-14: NWIRP to Lake Belton
Spikes in Perchlorate Data



Legend:	Stats:		
REPORTING LIMIT	Min: 4.0	Max: 4.0	Avg: 4.00
METHOD DETECTION LIMIT	Min: 1.0	Max: 1.0	Avg: 1.00
TRM1	Min: 0.5	Max: 111.0	Avg: 3.58
SC3	Min: 0.5	Max: 38.0	Avg: 2.02
SC5	Min: 0.5	Max: 7.6	Avg: 2.73



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Project:

BOSQUE AND LEON RIVER WATERSHEDS STUDY

Drawing Title:

CURRENT POSITION OF PERCHLORATE PLUME AT NWIRP (U. S. NAVY, DECEMBER 2003)

Sheet 1 of 1 Sheets

SCALE: 1:50,993

FIGURE: 5-15

5.1.2 Perchlorate Occurrence in Lakes

To assist in determining if perchlorate is present within Lake Waco and Lake Belton, the project team collected surface water samples from the lakes during separate field-sampling events. These sampling events included collecting several samples during delta area grid sampling, intake sampling (potable water and irrigation), and transect sampling as part of the Acoustic Doppler Current Profiler Study (ADCP) Study (See Section 5.1.4.2). Complete descriptions of the work completed during each of these studies are included below.

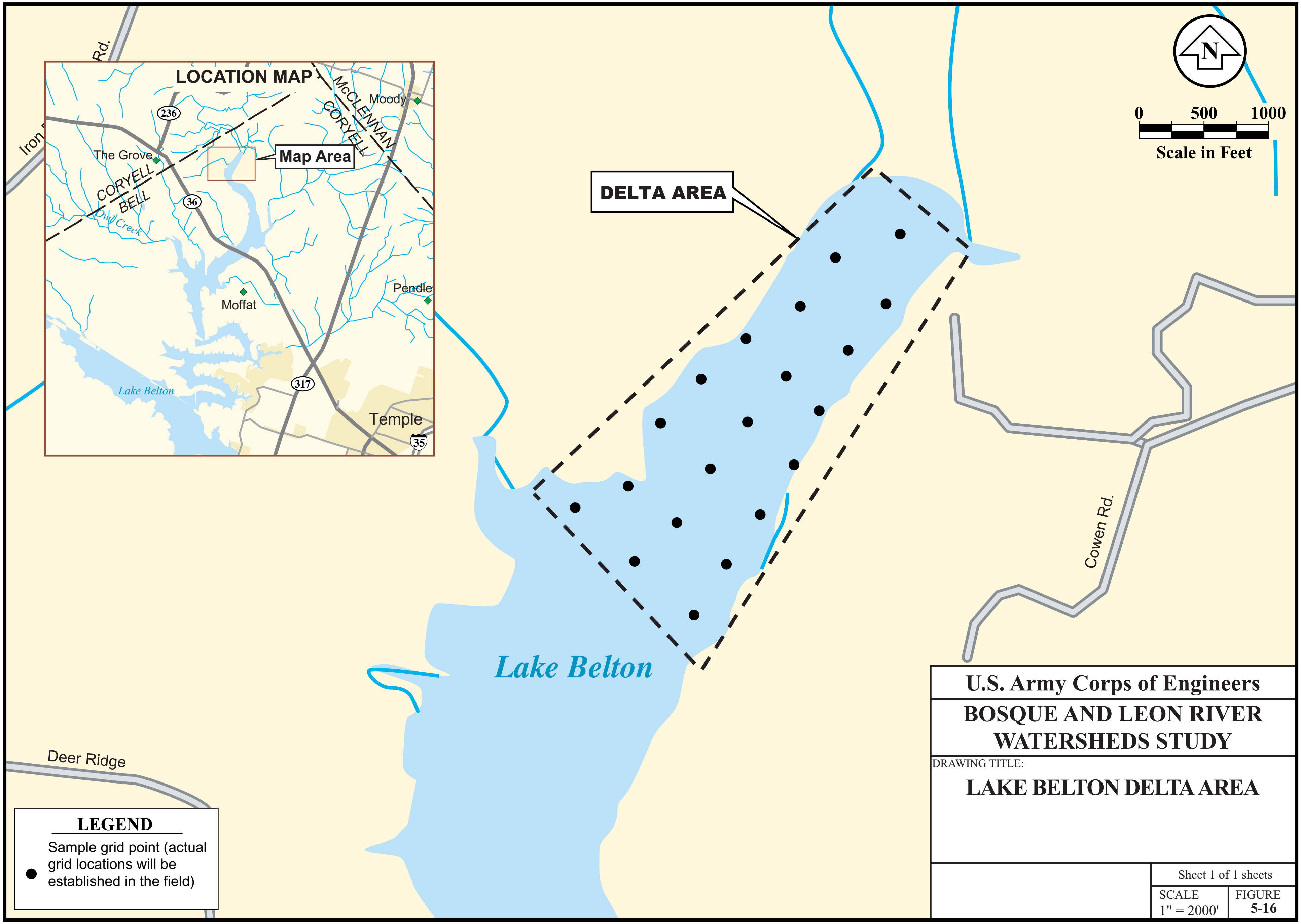
5.1.2.1 Delta Area Grid Sampling

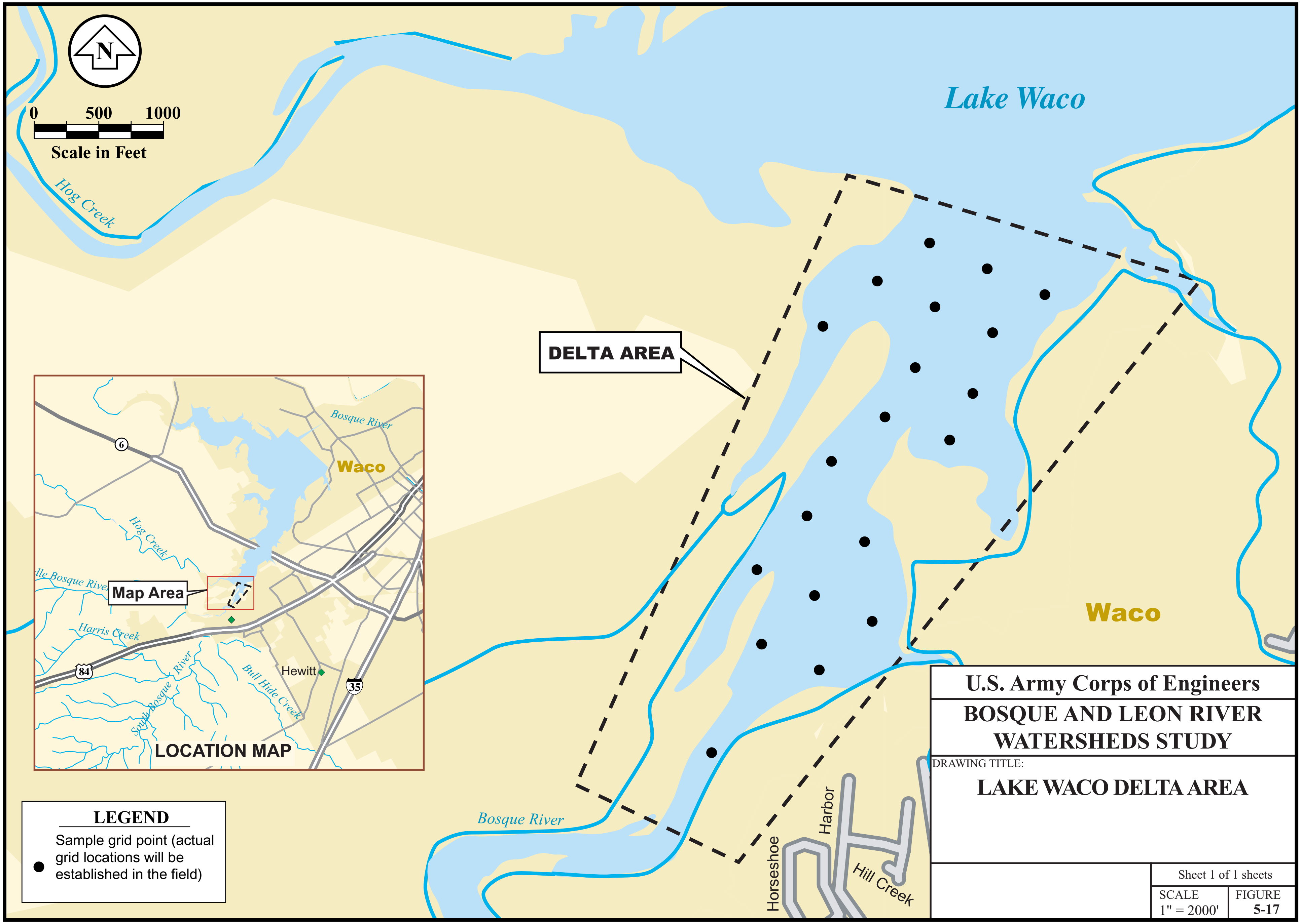
5.1.2.1.1 Introduction

The USACE project team collected surface water samples from grid locations within the delta areas of both Lake Belton and Lake Waco. This sampling was performed to evaluate the presence and distribution of perchlorate, if any, within these areas because they receive direct discharge from the Bosque and Leon River watersheds and they are the areas where the greatest sediment deposition is expected to occur in each lake. In addition to surface water sampling, sediment pore water sampling was also conducted within the delta area locations. The results of the surface water sampling activities are discussed within this section of the report and the sediment pore water results are presented in Section 5.2.1.2. This portion of the study was conducted as part of the Delta Areas Study. All the methodologies and protocol followed are detailed in the *Final Lake Belton and Lake Waco Delta Area Field Sampling Plan* (MWH, 2002c). Any deviations from the Field Sampling Plan are discussed further below.

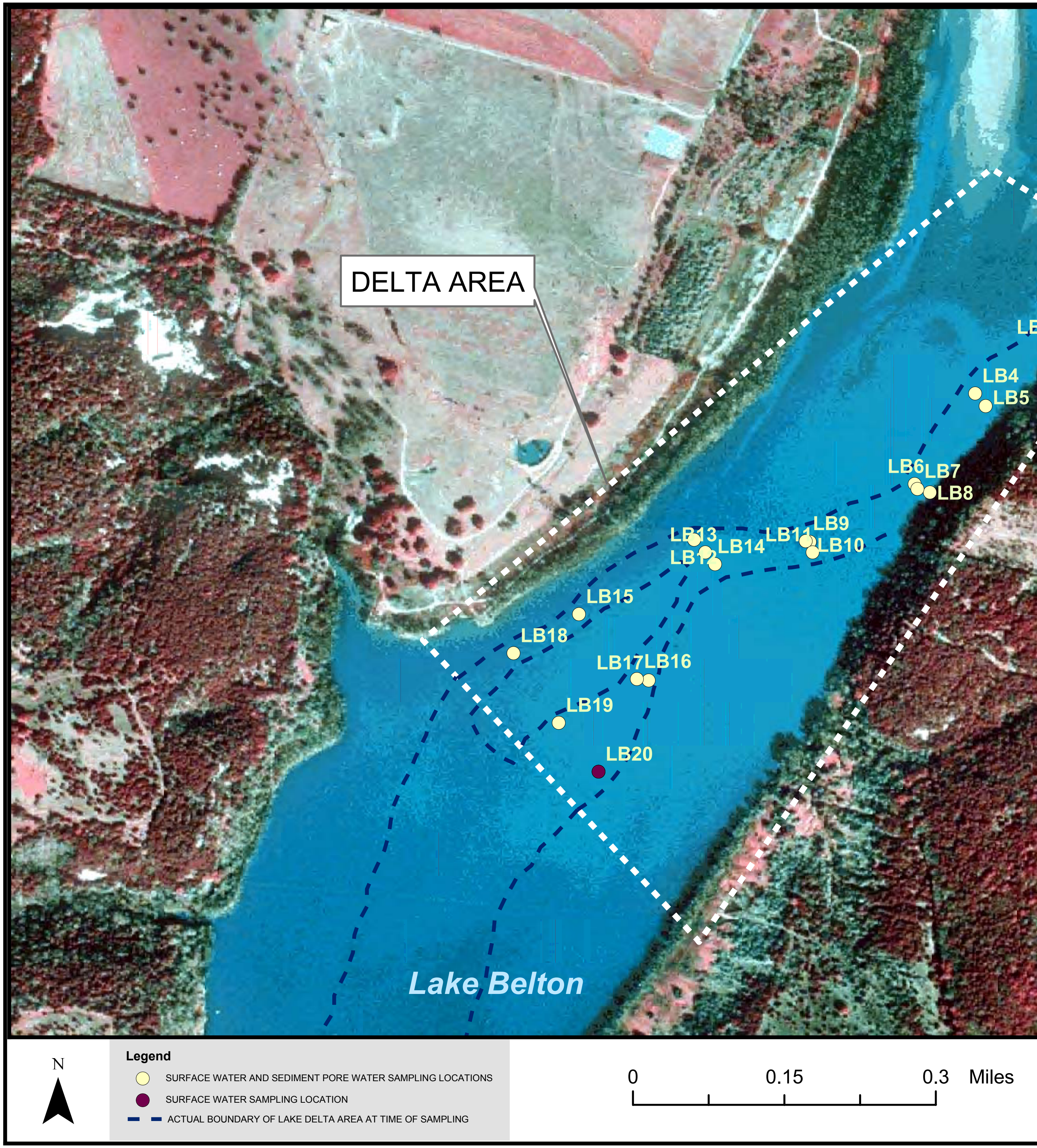
5.1.2.1.2 Methodology

The sampling of the delta areas of Lake Belton and Lake Waco was initially planned to be performed along a 20-point sample grid as shown in **Figure 5-16** and **Figure 5-17**, respectively. Due to the low lake water levels at the time of sampling and limited accessibility to various portions of the lakes, sampling was performed along transects. This longitudinal grid sampling pattern was chosen to minimize sample bias and to provide adequate coverage of the relatively large delta areas. Sample points were located using a boat and a Garmin GPS 76 instrument. The GPS information recorded at each grid point included latitude (degrees and minutes) and longitude (degrees and minutes) and are documented in **Table 5-3**. The locations of each sampling point and are shown in **Figure 5-18** and **Figure 5-19**.


LOCATION MAP
Map Area
The Grove
Moody
CORYELL
BELL
McCLENNAN
CORYELL
Owl Creek
236
36
317
35
Moffat
Pendle
Lake Belton
Temple
Iron
Rd.
DELTA AREA
N
0
500
1000
Scale in Feet
Cowen Rd.
Deer Ridge
Lake Belton
LEGEND
Sample grid point (actual grid locations will be established in the field)
U.S. Army Corps of Engineers
BOSQUE AND LEON RIVER WATERSHEDS STUDY
DRAWING TITLE:
LAKE BELTON DELTA AREA
Sheet 1 of 1 sheets
SCALE
1" = 2000'
FIGURE
5-16



N
0
500
1000
Scale in Feet
Lake Waco
Hog Creek
DELTA AREA
Waco
Bosque River
Horseshoe
Harbor
Hill Creek
Bosque River
Waco
6
Hog Creek
Map Area
dle Bosque River
Harris Creek
84
South Bosque River
Bull Hide Creek
Hewitt
35
LOCATION MAP
LEGEND
Sample grid point (actual grid locations will be established in the field)
U.S. Army Corps of Engineers
BOSQUE AND LEON RIVER WATERSHEDS STUDY
DRAWING TITLE:
LAKE WACO DELTA AREA
Sheet 1 of 1 sheets
SCALE
1" = 2000'
FIGURE
5-17



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Project:

BOSQUE AND LEON RIVER WATERSHEDS STUDY

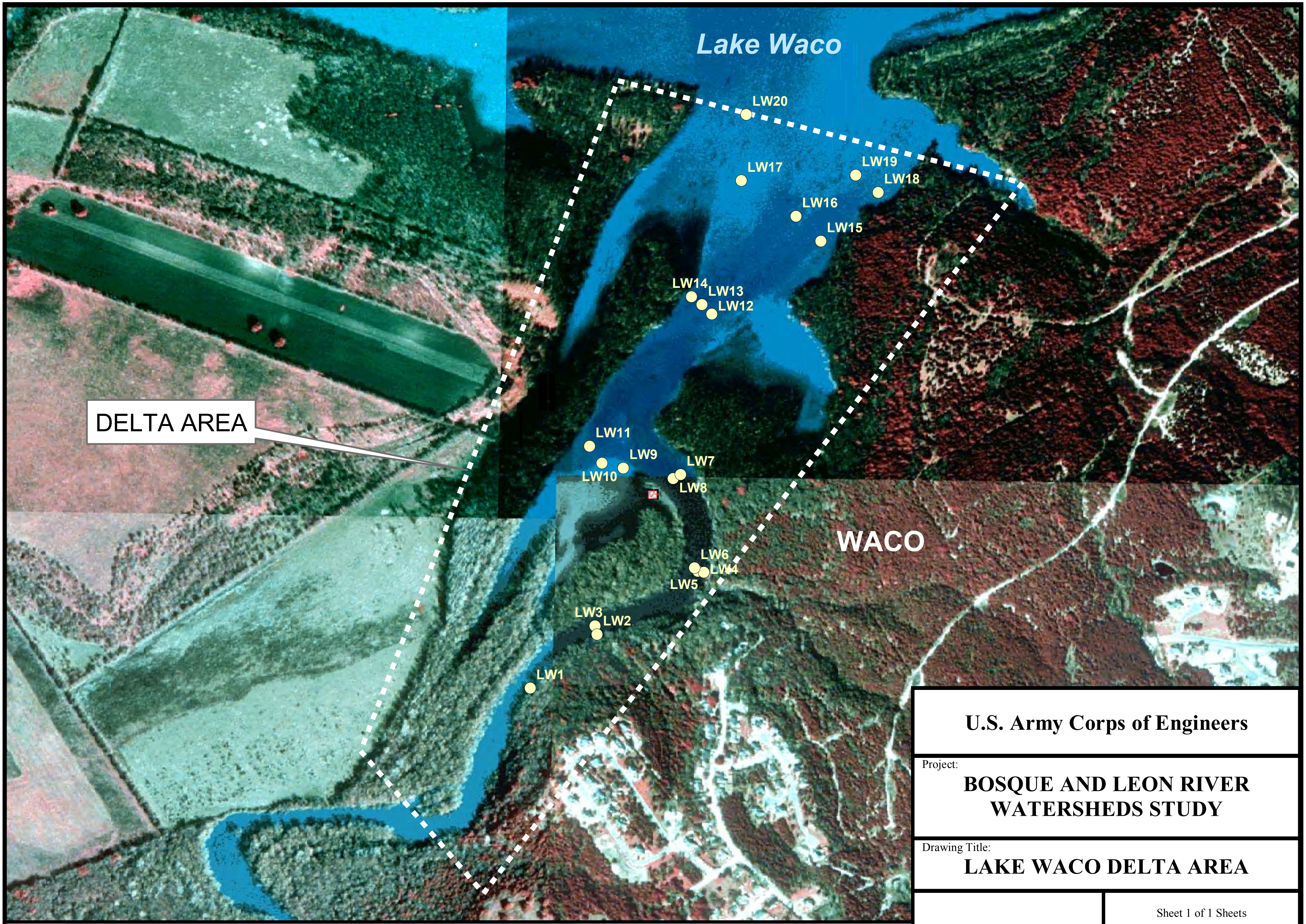
Drawing Title:

LAKE BELTON DELTA AREA

Sheet 1 of 1 Sheets

SCALE: 1:8,808

FIGURE: 5-18



N

Legend

SURFACE WATER AND SEDIMENT PORE WATER SAMPLING LOCATIONS

0 0.15 0.3 Miles

U.S. Army Corps of Engineers

Project:

BOSQUE AND LEON RIVER WATERSHEDS STUDY

Drawing Title:

LAKE WACO DELTA AREA

Sheet 1 of 1 Sheets

SCALE: 1:10,653

FIGURE: **5-19**

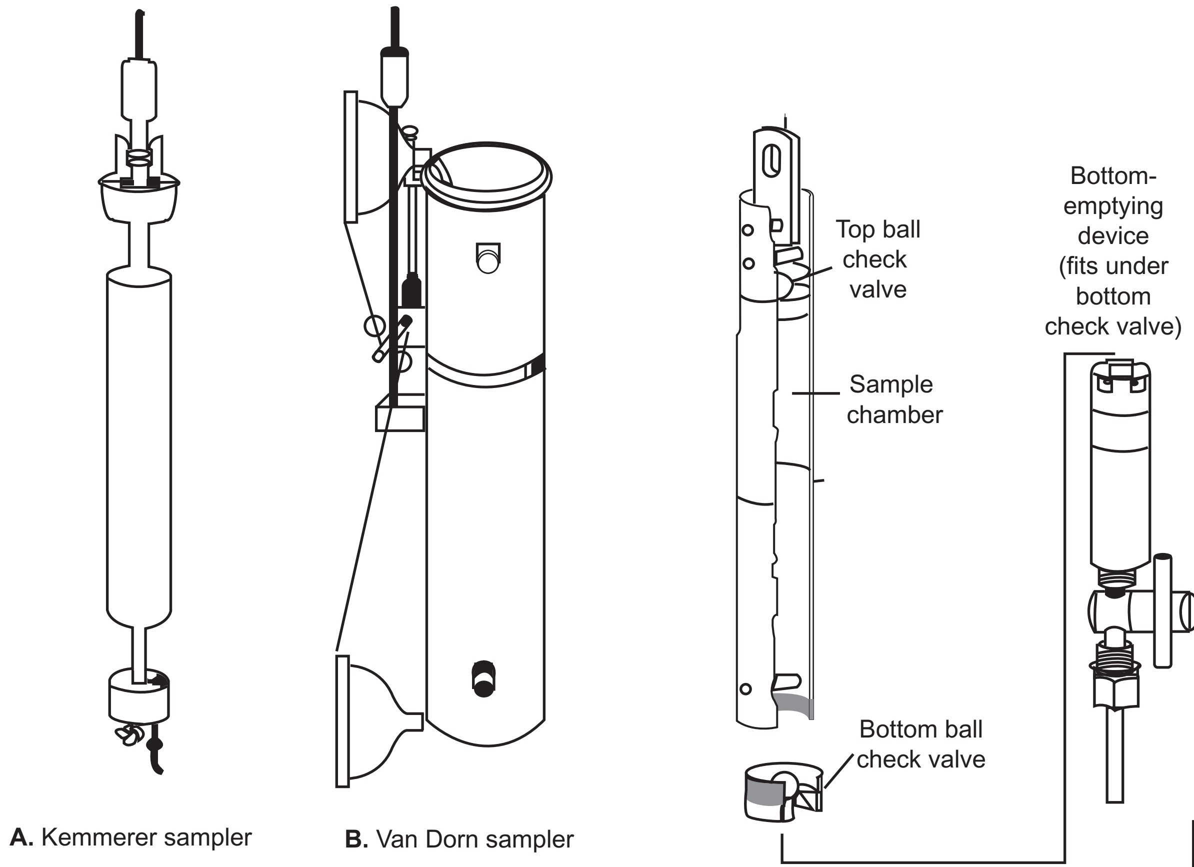
Table 5-3
Lake Belton and Lake Waco Delta Sampling Locations

Location	Lake	Latitude	Longitude
LB1	Lake Belton	31.27453	-97.46893
LB2	Lake Belton	31.27298	-97.46993
LB3	Lake Belton	31.27285	-97.46985
LB4	Lake Belton	31.27215	-97.47095
LB5	Lake Belton	31.27197	-97.47080
LB6	Lake Belton	31.27085	-97.47182
LB7	Lake Belton	31.27078	-97.47178
LB8	Lake Belton	31.27073	-97.47160
LB9	Lake Belton	31.27003	-97.47338
LB10	Lake Belton	31.27002	-97.47332
LB11	Lake Belton	31.26987	-97.47328
LB12	Lake Belton	31.27005	-97.47498
LB13	Lake Belton	31.26987	-97.47482
LB14	Lake Belton	31.26970	-97.47468
LB15	Lake Belton	31.26898	-97.47663
LB16	Lake Belton	31.26805	-97.47580
LB17	Lake Belton	31.26803	-97.47563
LB18	Lake Belton	31.26842	-97.47757
LB19	Lake Belton	31.26742	-97.47692
LB20	Lake Belton	31.26672	-97.47635
LW1	Lake Waco	31.49950	-97.25392
LW2	Lake Waco	31.50058	-97.25258
LW3	Lake Waco	31.50075	-97.25262
LW4	Lake Waco	31.50183	-97.25043
LW5	Lake Waco	31.50185	-97.25055
LW6	Lake Waco	31.50192	-97.25062
LW7	Lake Waco	31.50380	-97.25090
LW8	Lake Waco	31.50372	-97.25105
LW9	Lake Waco	31.50393	-97.25205
LW10	Lake Waco	31.50403	-97.25248
LW11	Lake Waco	31.50437	-97.25273
LW12	Lake Waco	31.50703	-97.25027
LW13	Lake Waco	31.50722	-97.25047
LW14	Lake Waco	31.50738	-97.25068
LW15	Lake Waco	31.50850	-97.24808
LW16	Lake Waco	31.50900	-97.24858
LW17	Lake Waco	31.50972	-97.24968
LW18	Lake Waco	31.50948	-97.24693
LW19	Lake Waco	31.50983	-97.24738
LW20	Lake Waco	31.51105	-97.24958

Once the sampling grid was established, surface water samples were collected from each of the grid points during a single sampling event on June 12, 2003 for Lake Belton and June 26, 2003 for Lake Waco. Each surface water sample was a discrete grab sample collected with an Alpha thief sampler. A photograph of this process is shown in **Figure 5-20**. Thief samplers consist of a cylinder with stoppers or check valves on each end. The samplers allow water to pass through the sample cylinder as it is lowered to the desired sampling depth. The stoppers are then activated to retain the sample prior to retrieval. The alpha thief sampler is shown on **Figure 5-21** (B. Van Dorn type).

Figure 5-20
Surface Water Sampling

Actual sample depths depended on whether the lake was thermally stratified at that sample location. Temperature profiles were initially established prior to collecting the surface water samples. At each grid location, a multi-parameter instrument (Hydrolab Mini Sonde 4a) was lowered through the water column in order to develop a vertical temperature profile. The temperature data were collected at 5-foot increments from the lake surface to the lake bottom and were recorded directly onto a copy of the Thermal Profile Graph. The completed graph was compared with **Figure 5-22**, which shows a thermal profile typical of a thermally stratified lake. If the thermal profile indicated the lake was thermally stratified (i.e., clear evidence of an epilimnion, thermocline, and hypolimnion as shown on **Figure 5-22**), then one surface water sample was collected from mid-depth in the epilimnion (upper layer) and another from mid-depth of the hypolimnion (lower layer). If the thermal profile indicated the lake was not stratified, one surface water sample was collected midway between the lake surface and the lake bottom.



A. Kemmerer sampler

B. Van Dorn sampler

C. Doublecheck-valve bailer and bottom-empyting device

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PROJECT:

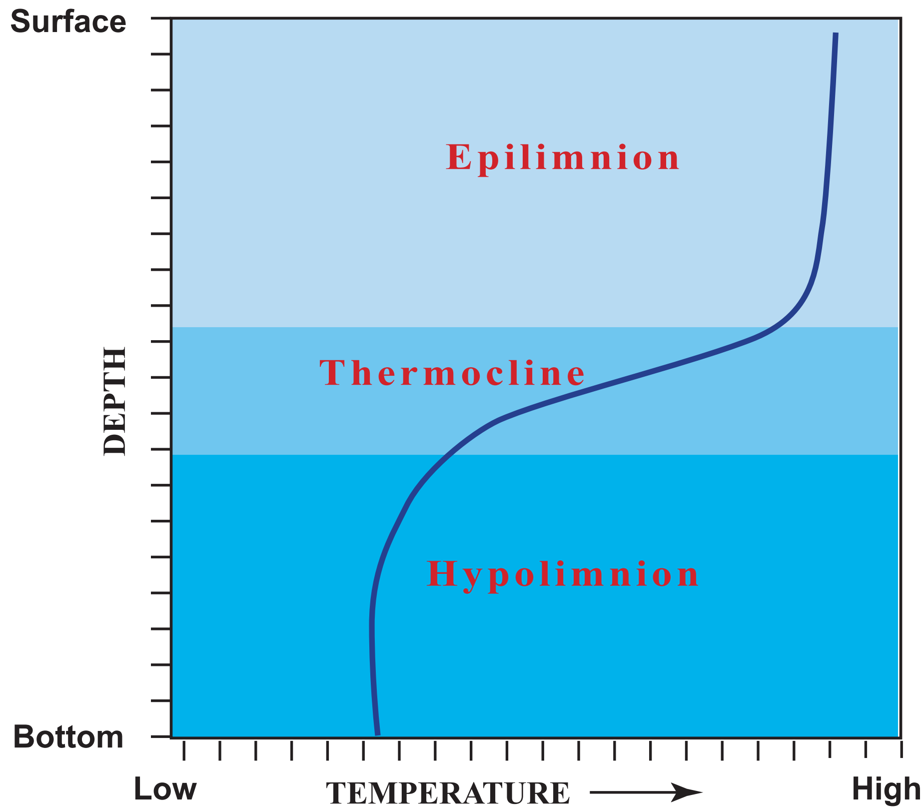
BOSQUE AND LEON RIVER WATERSHEDS STUDY

DRAWING TITLE:

THIEF SAMPLERS

Sheet 1 of 1 sheets

SCALE	FIGURE
No Scale	5-21



U.S. Army Corps of Engineers	
BOSQUE AND LEON RIVER WATERSHEDS STUDY	
DRAWING TITLE: TYPICAL THERMAL PROFILE OF A THERMALLY STRATIFIED LAKE	
	Sheet 1 of 1 sheets
	SCALE 1" = 2000' / FIGURE 5-22

Upon retrieval of the sampler, the sample was transferred to the appropriate sample containers. Since an Alpha sampler was used, one of the stoppers was opened and the sample carefully poured into the sample container. Sample containers and preservation requirements for the surface water samples are presented in the *Final Lake Belton and Lake Waco Delta Area Field Sampling Plan* (MWH, 2002c).

Field Observations. The following field observations and water quality measurements also were collected at each sampling location.

Field Observations:

- Cloud cover
- Wind velocity
- Secchi Disk transparency
- Water color
- Aquatic vegetation in percent cover (qualitative)

Water Quality Measurements (at each sampled location and depth):

- Temperature
- Dissolved oxygen
- Specific conductance
- pH
- Salinity
- Dissolved oxygen percent saturation

The water quality measurements were obtained by lowering the probe of the multi-parameter instrument to the sampled depth after the surface water samples were collected. All water quality and field observation data collected as part of this study are included for reference in **Appendix H**.

Duplicate Samples. At all sampling locations, blind duplicate and equipment blank samples were collected at a frequency to represent 10 percent of the environmental samples collected, and MS/MSD samples were collected at a frequency to represent 5 percent of the environmental samples collected.

Sample Designation. Each surface water sample was designated with an alphanumeric character string set apart by hyphens. For the samples collected from the delta area grid points, the designation began with the lake name abbreviation and grid number (e.g., "LB1" for Lake Belton grid point number 1, "LW1" for Lake Waco grid point number 1, etc.), followed by "SW" to indicate a surface water sample, and finally by the depth the sample was collected. For example, the surface water sample collected from Lake Belton grid point number 1 from 15 feet deep was designated "LB1-SW-15' ".

Blind duplicate surface water samples were designated with a fictitious number so the laboratory would not know where the sample was taken. For example, the first blind duplicate sample was designated “SW-1001”. The field crew kept careful records of the designations given to the blind duplicate samples and their corresponding environmental sample so that the analytical results could be correlated with the sample locations. Each MS/MSD sample had the same designation as its associated environmental sample except that “MS” or “MSD” followed the sample designation (e.g., “LB1-SW-15’ MS” and “LB1-SW-15’ MSD”). Each equipment blank sample had the same designation as its associated sampling location except that “EB” followed the sample designation (e.g., “LB1-SW-15’-EB”).

Sample Analysis. All surface water samples were analyzed for perchlorate by USEPA Method 314.0 at the USACE Engineer Research and Development Center Environmental Laboratory at the Environmental Chemistry Branch in Omaha, Nebraska. (See **Appendix V**). The USACE laboratory conformed to the analytical method requirements, analytical quality control requirements, instrument calibration frequency, and the laboratory quality control requirements presented in the QAPP (MWH, 2002e). A discussion of sample labeling, chain-of-custody, handling and shipping is presented in *Final Lake Belton and Lake Waco Delta Areas Field Sampling Plan* (MWH, 2002c). The data verification report for samples analyzed by the USACE laboratory is included in **Appendix W**.

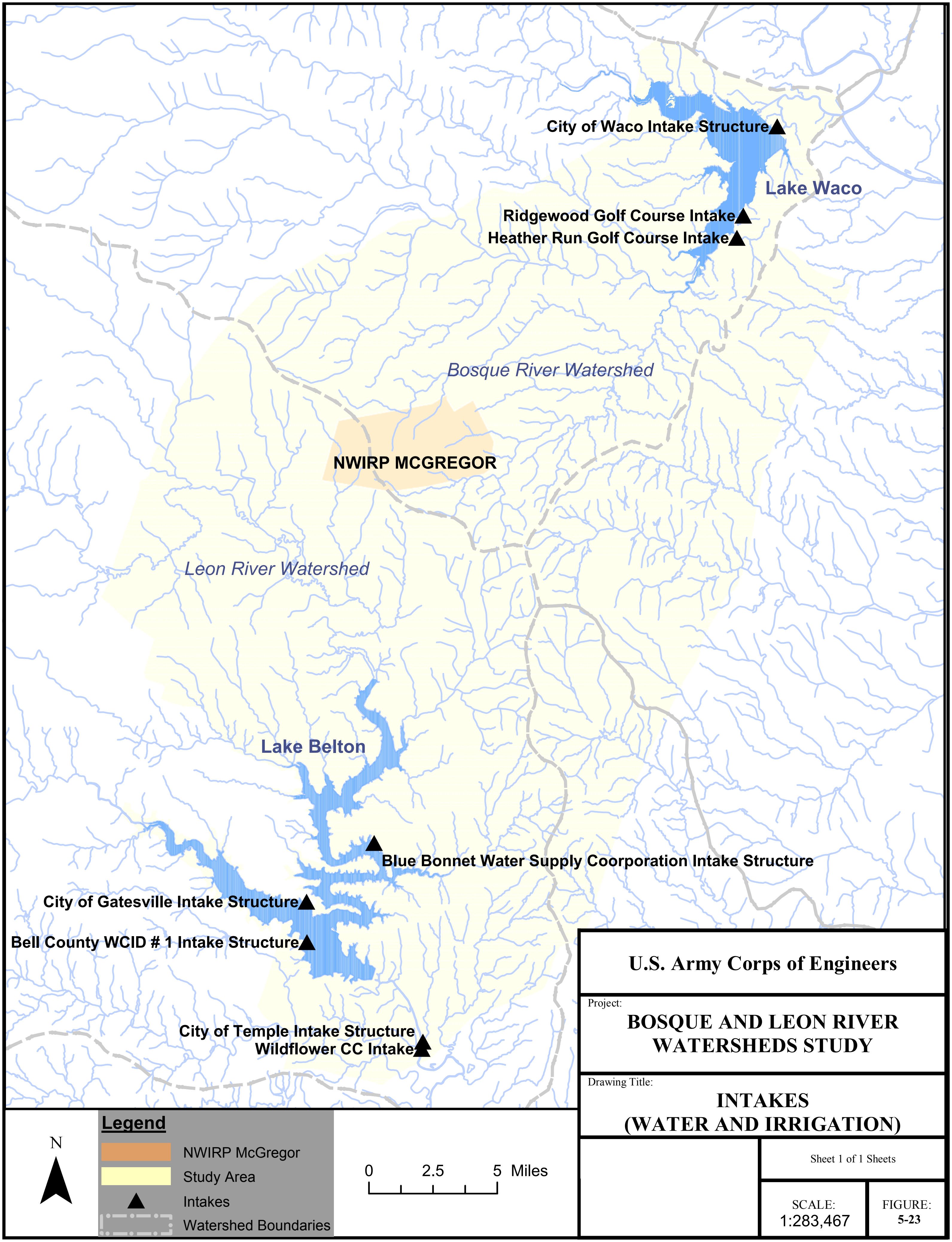
5.1.2.1.3 Data

A total of 20 water samples were collected from 20 sample locations within both Lake Belton and Lake Waco. Two duplicate samples were also collected from each lake during sampling activities. No perchlorate was detected in any of the 44 surface water samples collected from either Lake Belton or Lake Waco. The surface water sampling results for Lake Belton and Lake Waco are included in **Appendix I**. Perchlorate was also not detected in any of the equipment blank and investigations derived waste (IDW) samples collected during field activities. These results are also included in **Appendix I**.

5.1.2.2 Intake Sampling

5.1.2.2.1 Introduction

Surface water samples were collected from many of the drinking water and irrigation intakes located within Lake Waco and Lake Belton and downstream of the Lake Belton dam during the study. The names of the intakes, their physical locations and the type of intake are shown in **Figure 5-23** and documented in **Table 5-4**.



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Project:
BOSQUE AND LEON RIVER WATERSHEDS STUDY

Drawing Title:
INTAKES (WATER AND IRRIGATION)

Sheet 1 of 1 Sheets

SCALE: 1:283,467

FIGURE: 5-23

Table 5-4
Intake Types and Locations

Intake Name	ID	Type	Location	Latitude	Longitude	Method of Collection
Blue Bonnet Water Supply Corporation Intake Structure	BB	Drinking	Lake Belton	31.1826000	-97.4717000	Samples were collected from a hose bib at the raw water intake.
Bell County WCID # 1 Intake Structure	BC	Drinking	Lake Belton	31.1271000	-97.5168000	Samples were collected from a hose bib at the raw water intake location.
City of Gatesville Intake Structure	GV	Drinking	Lake Belton	31.1500000	-97.5167000	Samples were collected from a hose bib at the raw water intake.
Heather Run Golf Course Intake	HR	Irrigation	Lake Waco	31.5213100	-97.2264300	Grab Sample
Ridgewood Golf Course Intake	RW	Irrigation	Lake Waco	31.5338100	-97.2219700	Grab Sample
City of Temple Intake Structure	TP	Drinking	Downstream of Belton Dam	31.0700400	-97.4414500	Samples were collected directly from the lake using an Alpha thief sampler.
City of Waco Intake Structure	WA	Drinking	Lake Waco	31.5838890	-97.1986110	Collected by City of Waco
Wildflower CC Intake	WF	Irrigation	Downstream of Belton Dam	31.0659600	-97.4422100	Samples were collected directly from the surface water as a grab sample.

5.1.2.2.1.1 Potable Water

The U.S. Navy began collecting monthly surface water samples from all of the potable water intakes in both Lake Waco and Lake Belton and one location downstream of the Lake Belton dam in March 1999. The various intakes that were sampled in Lake Belton include the Bluebonnet intake, Bell County Water Control and Improvement District Number 1 intake, and the City of Gatesville intake. The location sampled downstream of the Lake Belton dam is the City of Temple intake. The water intake sampled in Lake Waco was the City of Waco intake located near the dam. The U.S. Navy decided to end this sampling effort in December 2002 since they had collected around 202 samples over a 45 month period and perchlorate concentrations in nearly all the samples were below detectable levels (See Section 5.1.2.4). Because of the importance of these drinking water supplies to the public, the project team agreed to continue collecting samples at each of these locations through December 2003 to complement the various other data being collected in the lakes by the project team. Because this sampling effort was not part of the original study scope, a Field Sampling Plan specific to this effort was not developed. Rather, all of the sampling methodologies and protocol followed during these sampling activities were derived from the *Final Lake Belton and Lake Waco Delta Areas Field*

Sampling Plan (MWH, 2002c). Any deviations from the Field Sampling Plan are discussed further below.

5.1.2.2.1.2 Irrigation

Surface water samples were collected from irrigation water intakes located in Lake Waco. These irrigation water intakes serve the Heather Run and Ridgewood Golf Courses. Surface water samples were also collected from the Wildflower Country Club irrigation intake downstream of Belton Dam. This portion of the Study was conducted as part of the Delta Areas Study. All of the methodologies and protocol followed are detailed in the *Final Lake Belton and Lake Waco Delta Areas Field Sampling Plan* (MWH, 2002c). Any deviations from the Field Sampling Plan are discussed further below.

5.1.2.2.2 Methodology

5.1.2.2.2.1 Potable

The various intakes from which samples were collected and methods of collection are described above in **Table 5-4**.

These water samples were collected in accordance with the thief sampling methodologies as discussed in Section 5.1.2.1.2 or direct sampling into appropriate containers from hose bib locations. Sample designation and analysis were performed as described for irrigation water intakes.

5.1.2.2.2.2 Irrigation

Surface water samples were collected within Lake Waco near the location of the irrigation water pump intakes serving the Heather Run (HR) and Ridgewood (RW) Golf Courses. In addition, surface water samples were collected from the Wildflower Country Club Irrigation Intake, which was also sampled previously by the U.S. Navy.

One surface water sample was collected from each golf course intake structure on a monthly basis for a period of 12 months. The locations of the irrigation pump intakes were documented using a Garmin GPS 76 instrument and included latitude (degrees and minutes) and longitude (degrees and minutes). At all sampling locations, blind duplicate and equipment blank samples were collected at a frequency to represent 10 percent of the environmental samples collected, and MS/MSD samples were collected at a frequency to represent 5 percent of the environmental samples collected.

Sample Designation. At the golf course intake structures, the sample designations were the golf course intake number (e.g., “HR” for the Heather Run intake structure and “RW” for the Ridgewood intake structure), followed by “SW” to indicate a surface water sample, and finally by the date and military time the sample was collected. For example, the surface water sample collected from the Heather Run Golf Course intake structure at 16:15 hours on November 18, 2002 would be designated “HR- SW-11-18-1615”.

Blind duplicate surface water samples were designated with a fictitious number so the laboratory would not know where the sample was collected. For example, the first blind duplicate sample was designated “SW-1001”. The field crew kept careful records of the designations given to the blind duplicate samples and their corresponding environmental sample so that the analytical results could be correlated with the sample locations. Each MS/MSD sample had the same designation as its associated environmental sample except that “MS” or “MSD” followed the sample designation (e.g., “LB1-SW-15’ MS” and “LB1-SW-15’ MSD”). Each equipment blank sample had the same designation as its associated sampling location except that “EB” followed the sample designation (e.g., “LB1-SW-15’-EB”).

Sample Analysis. All surface water samples were analyzed for perchlorate by USEPA Method 314.0 at the USACE Engineer Research and Development Center Environmental Laboratory at the Environmental Chemistry Branch in Omaha, Nebraska. (See **Appendix V**). The USACE laboratory conformed to the analytical method requirements, analytical quality control requirements, instrument calibration frequency, and the laboratory quality control requirements presented in the QAPP (MWH, 2002e). The data verification report for samples analyzed by the USACE laboratory is included in **Appendix W**.

5.1.2.2.3 Data

A total of 77 water samples, including three duplicates, were collected from the five potable water intakes over the course of this study. A total of 41 water samples, including nine duplicates, were collected from the two irrigation intakes in Lake Waco and the Wildflower Country Club irrigation intake over the course of this study. No perchlorate was detected in any of the samples collected from the intakes (potable or irrigation). The analytical results for both the irrigation water and potable water samples results are included in **Appendix J**.

5.1.2.3 Acoustic Doppler Current Profiler (ADCP) Sampling

5.1.2.3.1 Introduction

To assist in obtaining additional information regarding perchlorate concentrations within Lake Belton, additional surface water samples were collected from each of the 23 ADCP transect locations surveyed during the fall 2003 and winter 2003 events (see Section 5.1.4.2). This sampling was performed to collect data from identified preferential flow pathways encountered along each transect and to provide more focused sampling coverage within Lake Belton. Samples were collected along each transect in two locations: 1) above and below the thermocline at the deepest point along the transect, and 2) within preferential flow pathways that were identified along the transect. All of the methodologies and protocols followed during this sampling were derived from the *Final Lake Belton and Lake Waco Delta Areas Study Field Sampling Plan* (MWH, 2002c). Any deviations from the Field Sampling Plan are discussed further below.

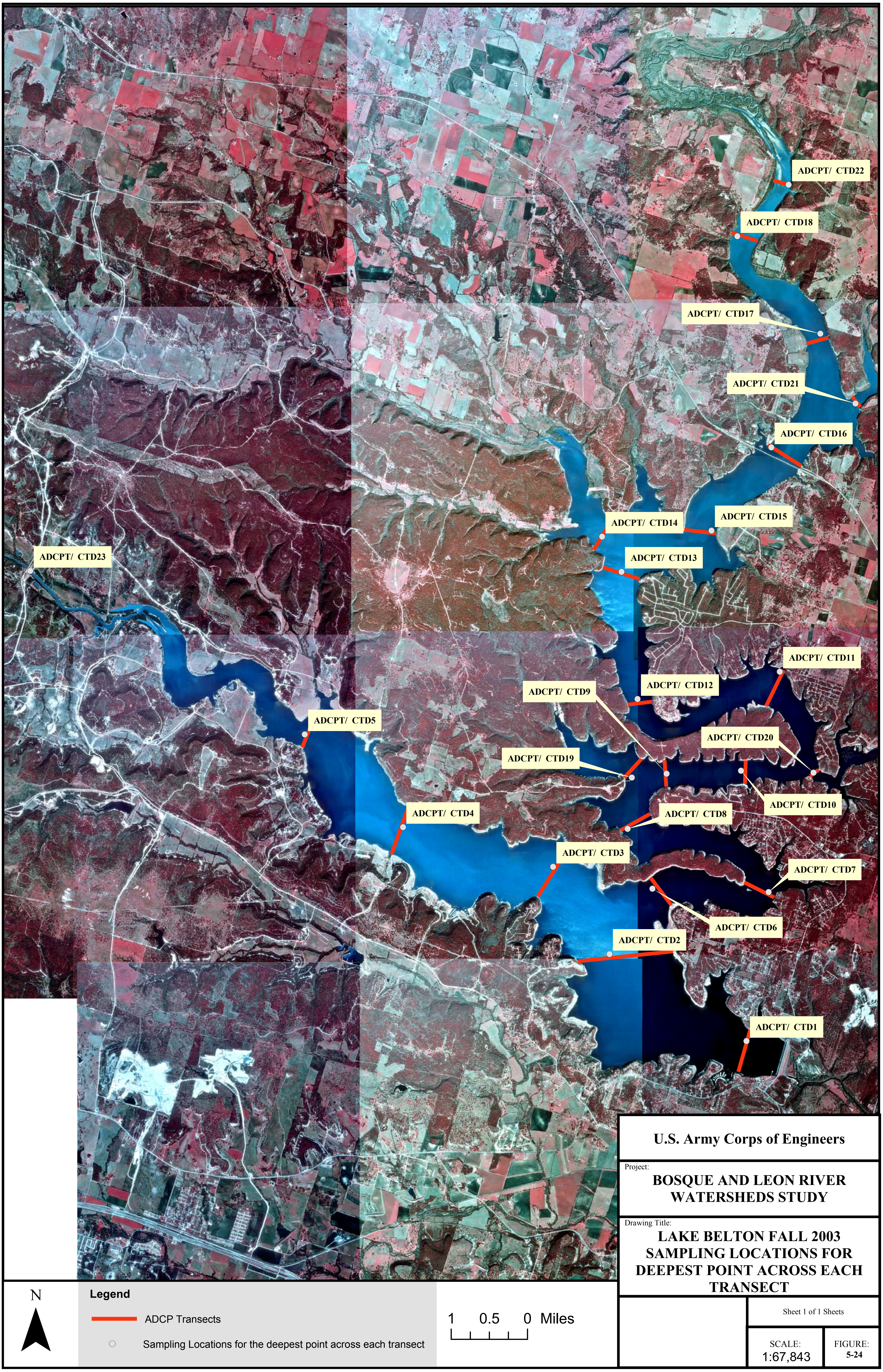
5.1.2.3.2 Methodology

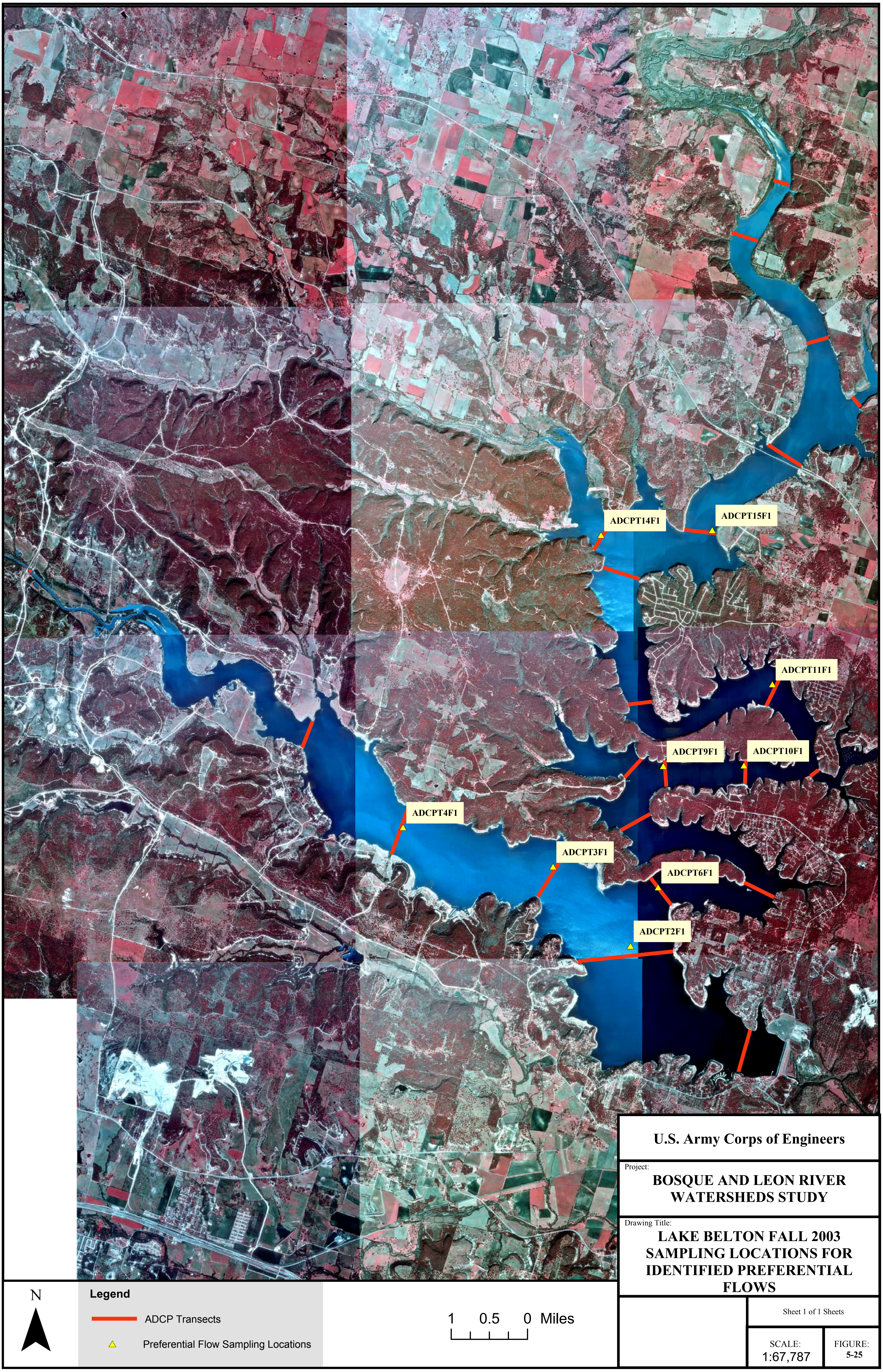
Initially, two surface water samples were collected at the deepest point along each transect. The first sample was collected from the epilimnion (upper layer) 5 feet below the surface and the second sample was collected in the hypolimnion (lower layer) 5 feet above the water/ sediment interface. If the depth was less than 10 feet, one surface water sample was collected from mid-depth. If there was significant preferential flow detected across the transect, a water sample was also collected at the location depth of the identified preferential flow. The sample collection locations were documented using a Garmin GPS 76 instrument and included latitude (degrees and minutes) and longitude (degrees and minutes). The actual GPS coordinates of the sampling locations for the deepest point across each transect and preferential flows identified for the Fall 2003 and Winter 2003 surveys are documented in **Appendix K**. The actual sampling locations for the deepest point across each transect and preferential flows identified for the fall 2003 and winter 2003 surveys are shown in **Figure 5-24** through **Figure 5-27**. A total of 106 samples were collected during these surveys. Each surface water sample was a discrete "grab" type sample collected with an Alpha thief sampler as previously discussed in Section 5.1.2.1.2.

At all sampling locations, blind duplicate and equipment blank samples were collected at a frequency to represent 10 percent of the environmental samples collected, and MS/MSD samples were collected at a frequency to represent 5 percent of the environmental samples collected.

Sample Designation. Each surface water sample was designated with an alphanumeric character string set apart by hyphens. For the samples collected from the deepest point across the transect, the designation began with the ADCP transect abbreviation and number (e.g., "ADCPT1" for transect 1, etc.), followed by "SW" to indicate a surface water sample, and finally by the depth the sample was collected. For example, the surface water sample collected from transect 12 from 15 feet deep was designated "ADCPT12-SW-15' ". For the samples collected from the flow area across the transect, the designation began with the ADCP transect abbreviation and number (e.g., "ADCPT1" for transect 1, etc.), followed by "F" to indicate a flow sample, followed by a number to indicate the number of flows detected across the transect, followed by "SW" to indicate a surface water sample, and finally by the depth the sample was collected. For example, the first surface water sample collected due to flow from transect 15 at a depth of 12 feet was designated "ADCPT12F1-SW-15' ".

Blind duplicate surface water samples were designated with a fictitious number so the laboratory would not know where the sample was collected. For example, the first blind duplicate sample was designated "SW-1001". The field crew kept careful records of the designations given to the blind duplicate samples and their corresponding environmental sample so that the analytical results could be correlated with the sample locations. Each MS/MSD sample had the same designation as its associated environmental sample except that "MS" or "MSD" followed the sample designation (e.g., "ADCPT12F1-SW-15' MS" and "ADCPT12F1-SW-15' MSD"). Each equipment blank sample had the same designation as its associated sampling location except that "EB" followed the sample designation (e.g., "ADCPT12F1-SW-15' -EB").


ADCPT/ CTD22
ADCPT/ CTD18
ADCPT/ CTD17
ADCPT/ CTD21
ADCPT/ CTD16
ADCPT/ CTD14
ADCPT/ CTD15
ADCPT/ CTD13
ADCPT/ CTD23
ADCPT/ CTD11
ADCPT/ CTD12
ADCPT/ CTD9
ADCPT/ CTD5
ADCPT/ CTD20
ADCPT/ CTD19
ADCPT/ CTD10
ADCPT/ CTD8
ADCPT/ CTD4
ADCPT/ CTD3
ADCPT/ CTD7
ADCPT/ CTD6
ADCPT/ CTD2
ADCPT/ CTD1
U.S. Army Corps of Engineers
Project:
BOSQUE AND LEON RIVER WATERSHEDS STUDY
Drawing Title:
LAKE BELTON FALL 2003 SAMPLING LOCATIONS FOR DEEPEST POINT ACROSS EACH TRANSECT
N
Legend
ADCP Transects
Sampling Locations for the deepest point across each transect
1 0.5 0 Miles
Sheet 1 of 1 Sheets
SCALE:
1:67,843
FIGURE:
5-24



U.S. Army Corps of Engineers

Project:

BOSQUE AND LEON RIVER WATERSHEDS STUDY

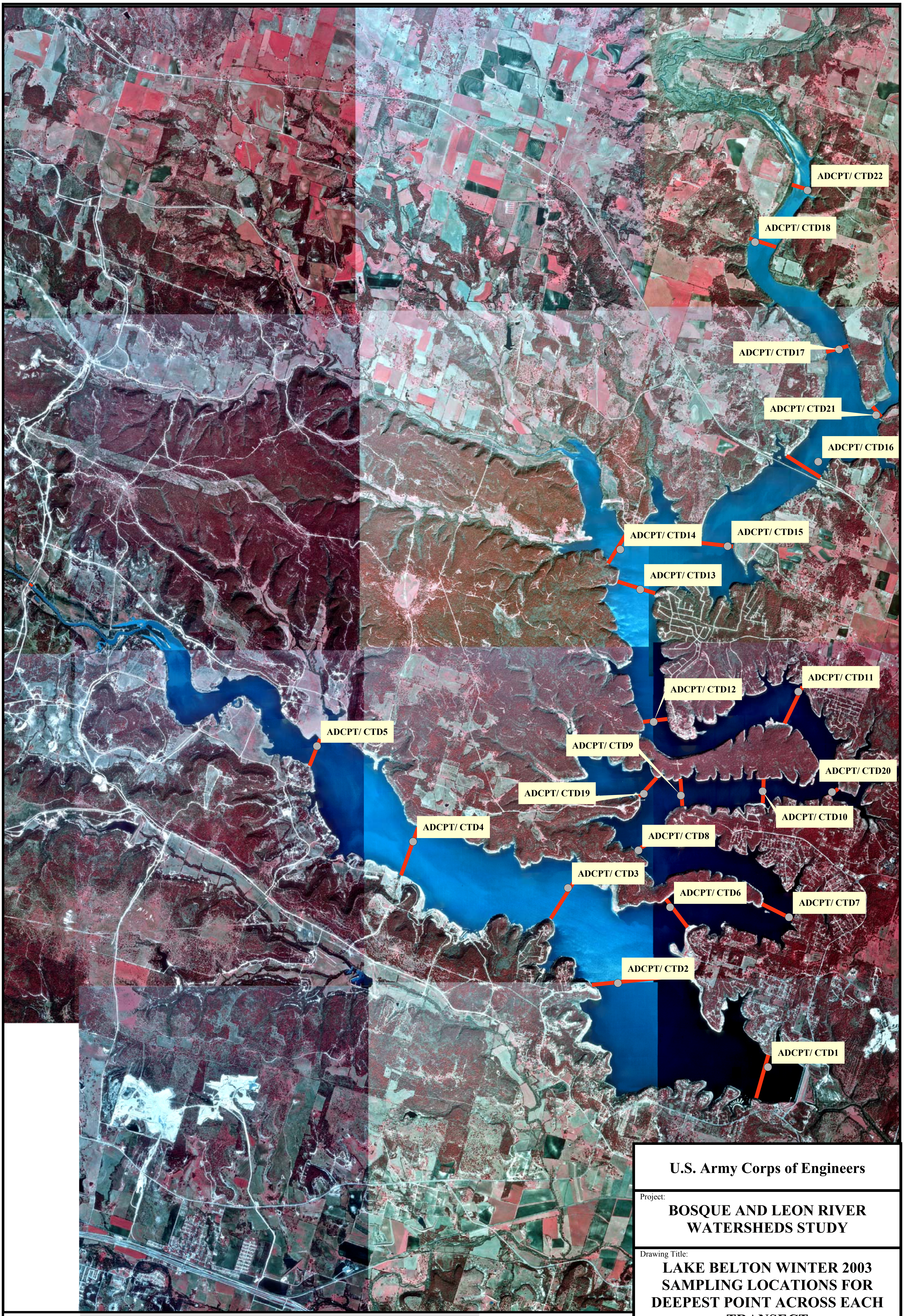
Drawing Title:

LAKE BELTON FALL 2003 SAMPLING LOCATIONS FOR IDENTIFIED PREFERENTIAL FLOWS

Sheet 1 of 1 Sheets

SCALE: 1:67,787

FIGURE: 5-25



U.S. Army Corps of Engineers

Project:

BOSQUE AND LEON RIVER WATERSHEDS STUDY

Drawing Title:

LAKE BELTON WINTER 2003 SAMPLING LOCATIONS FOR DEEPEST POINT ACROSS EACH TRANSECT

N

Legend

ADCP Transects

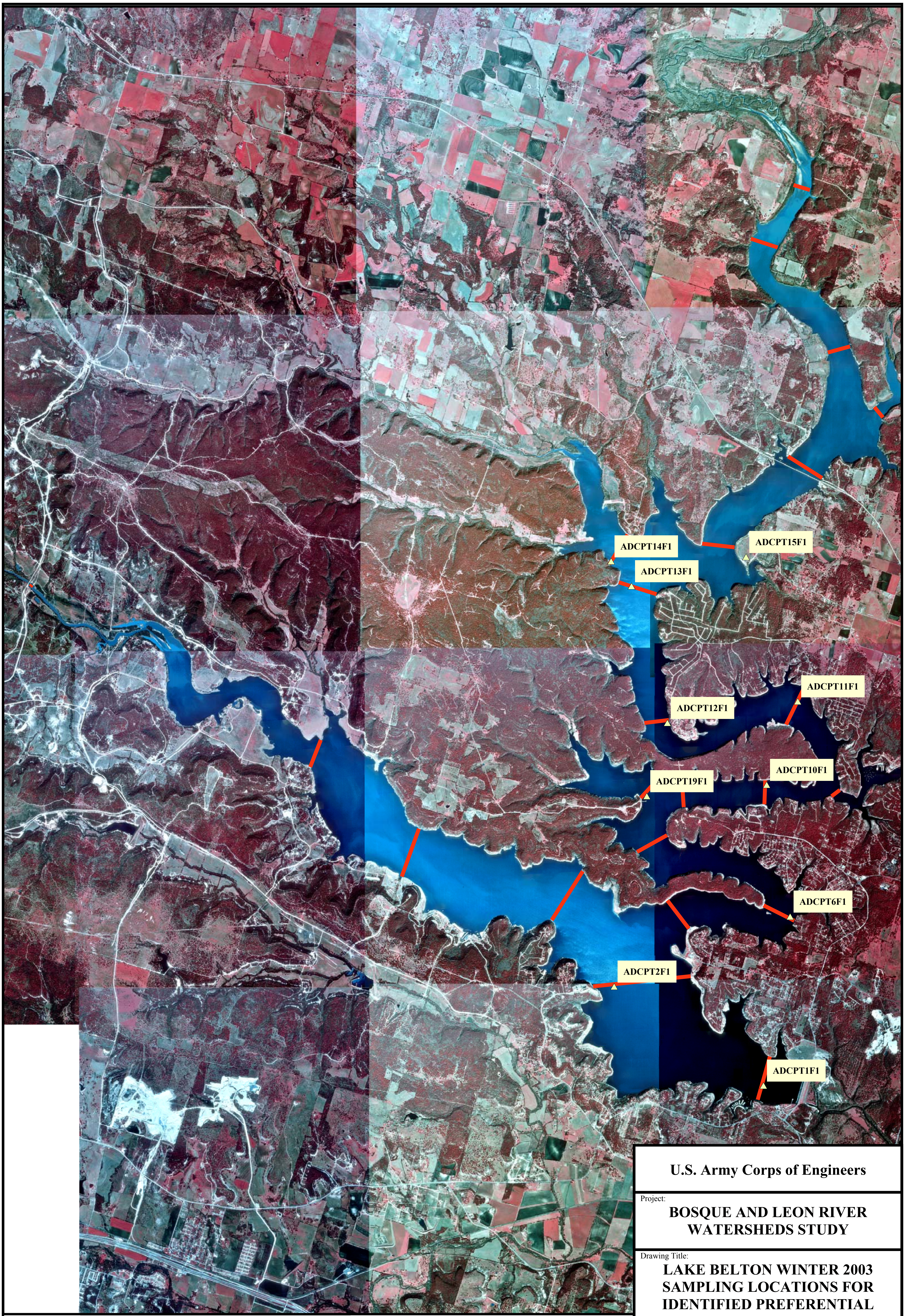
Sampling Locations for the deepest point across each transect

1 0.5 0 Miles

Sheet 1 of 1 Sheets

SCALE: 1:67,843

FIGURE: 5-26



N

Legend

ADCP Transects

Preferential Flow Sampling Locations

1 0.5 0 Miles

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BOSQUE AND LEON RIVER WATERSHEDS STUDY

Drawing Title:

LAKE BELTON WINTER 2003 SAMPLING LOCATIONS FOR IDENTIFIED PREFERENTIAL FLOWS

Sheet 1 of 1 Sheets

SCALE: 1:67,843

FIGURE: 5-27

Sample Analysis. All surface water samples were analyzed for perchlorate by USEPA Method 314.0 at the USACE Engineer Research and Development Center Environmental Laboratory at the Environmental Chemistry Branch in Omaha, Nebraska (See **Appendix V**). The USACE laboratory conformed to the analytical method requirements, analytical quality control requirements, instrument calibration frequency, and the laboratory quality control requirements presented in the QAPP (MWH, 2002e). The data verification report for samples analyzed by the USACE is included in **Appendix W**.

5.1.2.3.3 Data

A total of 40 water samples (including three duplicate samples) were collected from the deepest point across 23 ADCP transects and a total of 11 preferential flow samples (including two duplicate samples) were collected during the fall 2003 sampling event. A total of 43 samples (including four duplicate samples) were collected from the deepest point across the 22 ADCP transects and a total of 11 preferential flow samples (including one duplicate sample) were collected during the winter 2003 event. No perchlorate was detected in any of the ADCP samples collected during these studies. Analytical findings for the deepest point across each transect and flows for the Fall 2003 survey and the Winter 2003 survey are included in **Appendix L**.

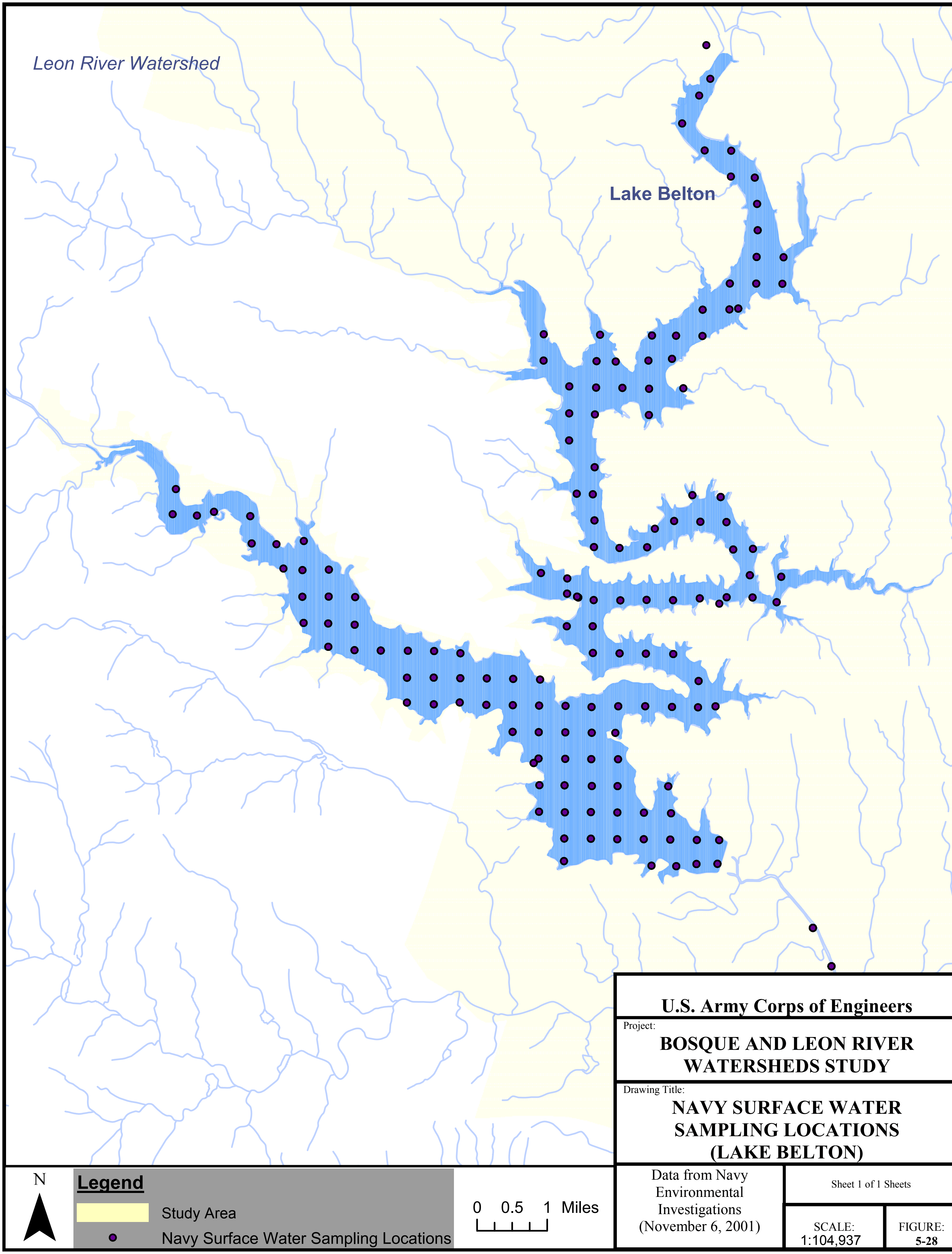
5.1.2.4 Historical Data

5.1.2.4.1 Introduction

The U.S. Navy conducted surface water sampling in both Lake Belton and Lake Waco between 1998 and 2001. The locations of surface water sampling for Lake Belton and Lake Waco are shown in **Figure 5-28** and **Figure 5-29**, respectively. The most extensive sampling in the lakes was conducted as part of the Phase III Groundwater Investigation at NWIRP McGregor. During this investigation, the U.S. Navy assessed water quality at Lake Belton and Lake Waco. The lake assessment approach is presented in *Lake Water Quality Assessment Work Plan* (EnSafe, 2000a). This investigation was designed to complete a thorough, yet expedited, environmental assessment of perchlorate in the lakes and produce data that could be used to assess risk to human health and the environment. EnSafe conducted two sampling events in spring 2000 and summer 2000. The Spring 2000 sampling event was conducted to assess the lakes under cool weather, cool water conditions, while the Summer 2000 sampling event was conducted to assess the lakes under warm weather, warm water conditions. The U.S. Navy also sampled all the potable water intakes in Lake Belton and Lake Waco monthly since March 1999.

5.1.2.4.2 Methodology

The U.S. Navy has completed extensive perchlorate sampling in both Lakes Belton and Waco. The overall approach, sampling techniques, and methods used for lake assessments are described in detail in the *NWIRP McGregor Final Groundwater Investigation Work Plan* (EnSafe, 1998b).



U.S. Army Corps of Engineers

Project:
BOSQUE AND LEON RIVER WATERSHEDS STUDY

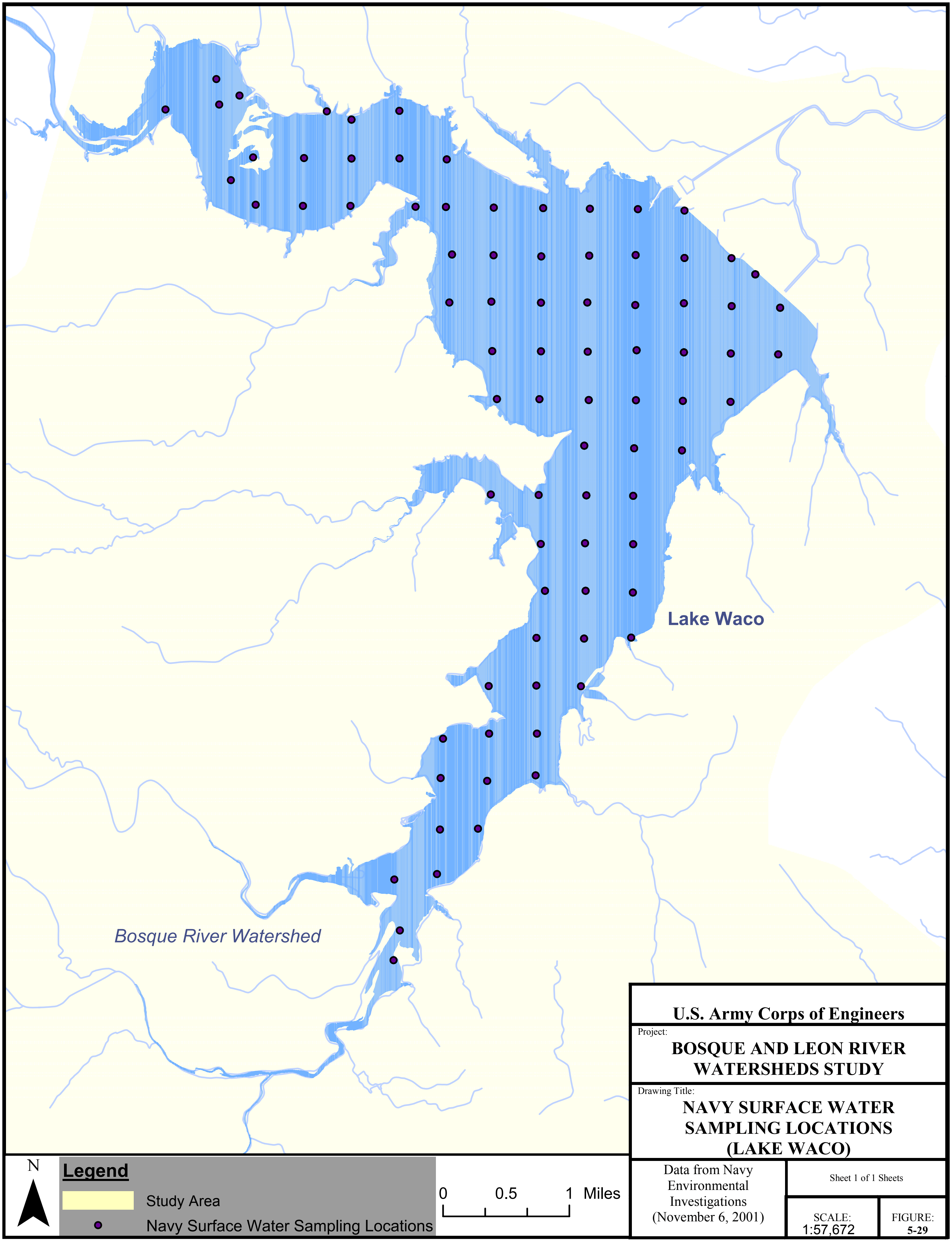
Drawing Title:
NAVY SURFACE WATER SAMPLING LOCATIONS (LAKE BELTON)

Data from Navy Environmental Investigations (November 6, 2001)

Sheet 1 of 1 Sheets

SCALE: 1:104,937

FIGURE: 5-28



U.S. Army Corps of Engineers

Project:
BOSQUE AND LEON RIVER WATERSHEDS STUDY

Drawing Title:
NAVY SURFACE WATER SAMPLING LOCATIONS (LAKE WACO)

Data from Navy Environmental Investigations (November 6, 2001)

Sheet 1 of 1 Sheets

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FIGURE: 5-29

Lake Belton and Lake Waco underwent two seasonal sampling events: a "cool water" event in the spring and a "warm water" event in the summer. Identical field protocols were used for each lake. To provide a sample representative of the lake surface water during each event, a 2,000-foot by 2,000-foot sampling grid was established in each lake. The sampling grids are presented as **Figure 5-28** and **Figure 5-29**.

Before collecting analytical samples, EnSafe personnel recorded the chemical and physical profile of the water column at each grid location, regardless of depth. The probe of a calibrated Horiba U-23 data logger was placed overboard and suspended with sensors just below the water surface to equilibrate. The activated datalogger was slowly hand lowered to the lake bottom, collecting a set of real-time readings during its descent. The Horiba U-23, attached to a laptop computer, measured and recorded these location specific parameters.

- pH
- Temperature
- Conductivity
- Turbidity
- Dissolved Oxygen (DO)
- Depth
- Salinity
- Total Dissolved Solids (TDS)
- Oxidation/ Reduction Potential (ORP)
- Specific Gravity
- Chloride ion (Cl^-)
- Ammonium ion (NH_4^+)
- Nitrate ion (NO_3^-)

As the Horiba measurements were being recorded and the profiles graphed, the sampling crew prepared to collect the surface water samples. Depending on water depth, up to three water samples were collected at each location. If the water depth was less than 10 feet, only one sample was collected at the bottom of the lake just above the sediment surface (hypolimnion). If the depth was between 10 and 30 feet, a surface (epilimnion) sample was also collected. If water depth was greater than 30 feet, surface, bottom, and intermediate (metalimnion) samples were collected. The primary determining factor in selecting the collection depth of the intermediate sample proved to be the temperature gradients. During both profiling events, no discernable variations in conductivity (an alternate indicator) were observed at each lake. If the water profile/graphs showed a distinct change in temperature (thermocline), or even if a minimal gradient resulted in a curved graph, an intermediate water sample was collected from immediately below it, presuming that cooler, denser water would exhibit higher perchlorate concentrations.

If a temperature gradient was absent or if the thermocline was near the bottom, the intermediate sample was collected at mathematical mid-depth. In water 30 feet or less, the intermediate sample was omitted to avoid sample redundancy.

To collect a discrete grab water sample, a messenger-activated 1.2-liter stainless steel Kemmerer bottle with a graduated line was used.

The U.S. Navy collected samples from the potable water intakes and the Wildflower Country Club irrigation intake in the study area previously discussed in Section 5.1.2.2.1. These samples were collected in accordance with the thief sampling methodologies described in Section 5.1.2.1.2 or direct sampling into appropriate containers from hosebib locations.

5.1.2.4.3 Data

Detailed observations, and findings made during both the sampling events are provided in the *Final Draft Report Lake Water Quality Assessment* (EnSafe, 2000b). A summary of these findings is presented below.

A total of 336 water samples were collected from 141 sample locations in Lake Belton during the Spring 2000 sample collection event and 331 water samples were submitted from 143 locations during the Summer 2000 event. Additionally, a total of 150 surface water samples were collected from 78 sample locations in Lake Waco during the Spring 2000 sample collection event and 142 water samples were collected from 82 sampling locations during the Summer 2000 event.

The following briefly describes the laboratory findings for both the lakes, as reported by the U.S. Navy.

- **Spring 2000 (Cool Water)** - Perchlorate was not detected in any lake water samples analyzed at or above 4 µg/L and no water sample had an estimated perchlorate concentration less than 4 µg/L, the pratical quantitation limit (PQL).
- **Summer 2000 (Warm Water)** – Perchlorate was detected in a single water sample from Lake Waco during the summer sampling event. Intermediate water sample WACW204102 from the center of the lake, 23 feet below the surface had a perchlorate detection of 17.4 µg/L reported by the laboratory. The surface water and bottom interval samples from this location were below detectable levels for perchlorate. The U.S. Navy data validator reviewed the laboratory's findings and flagged the 17.4 µg/L result with a "J" qualifier, meaning it is an estimated value. A memorandum discussing the validation steps for this single perchlorate detection and rationale for no further action is provided in detail in Appendix I of the *Final Draft Report Lake Water Quality Assessment* (EnSafe, 2000b). The location of this sample is shown in **Figure 5-30**. The U.S. Navy decided that that they would continue to report the detection as 17.4 µg/L "J". However, based on the analytical measures performed by the laboratory and a comparison to data collected from the

> sample point and surrounding points, the U.S. Navy concluded that the isolated detection of perchlorate in Lake Waco should be considered an unreproducable anomaly and not representative of contamination in Lake Waco.

Of all the 959 lake water samples collected during both sampling events, the U.S. Navy reported only one questionable detection, which represents 0.1% of the samples. The analytical data for this investigation are discussed in detail in the *Final Draft Report Lake Water Quality Assessment* (EnSafe, 2000b).

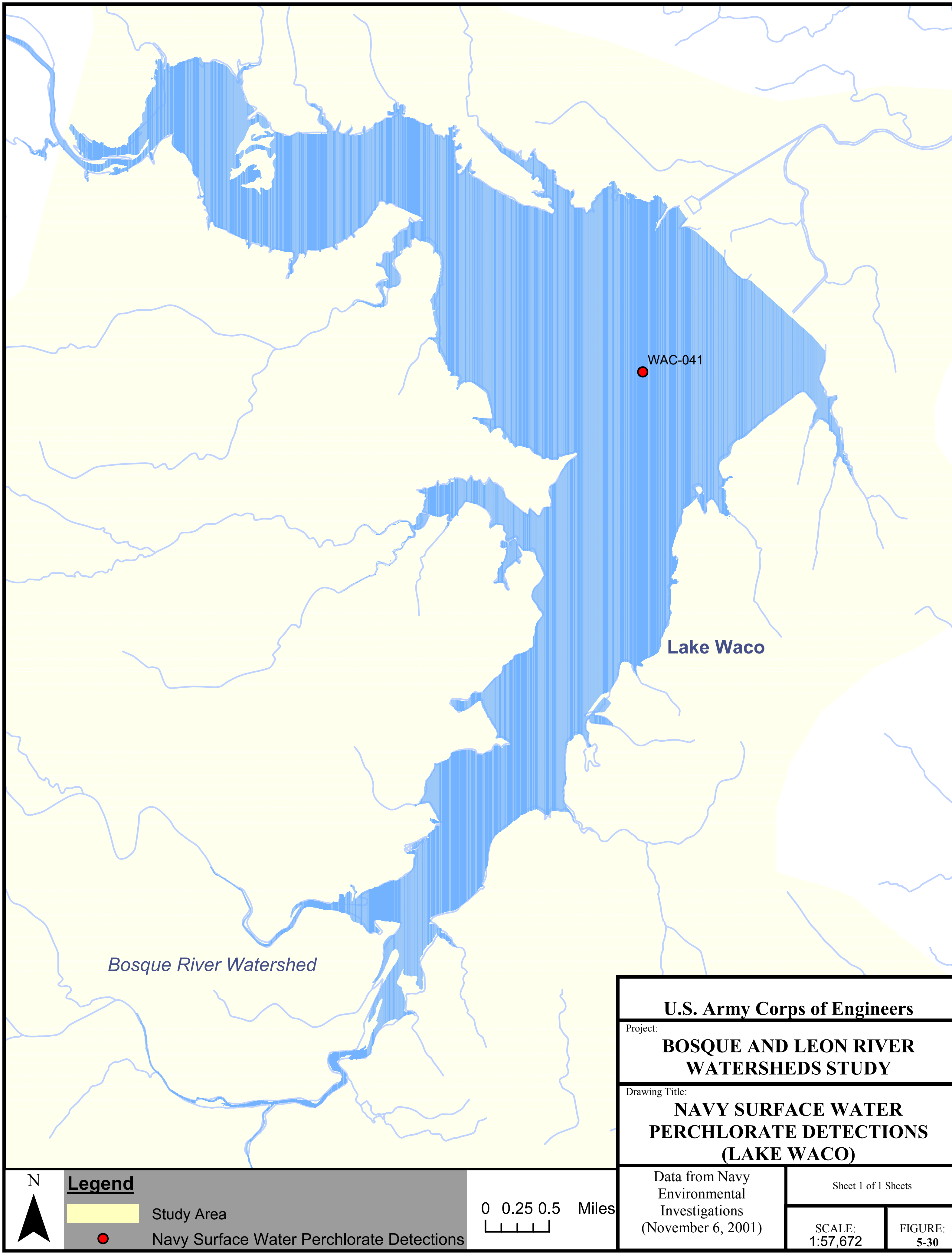
However, based on a review of previous EnSafe reports, MWH confirmed that there has been one other perchlorate detection that has occurred in Lake Belton as part of U.S. Navy studies. This sample was collected from the southern portion of Lake Belton (BEL-071, 7 µg/L).

The U.S. Navy collected a total of around 243 intake samples at Lake Intakes since February 1999 through December 2002. Most of the monthly samples collected by the U.S. Navy from the five water intakes have been below detection levels for perchlorate. The only three detections that have occurred in the intakes sampled by the U.S. Navy were at the Bell County Raw-Water Intake (INBL-1, 4.1 µg/l in October 1999) and the Wildflower Country Club irrigation intake (INLR-2, 0.67 µg/l in March 1999 and 6 µg/l in July 2000).

The locations of all samples that had perchlorate detections in Lake Belton are shown in **Figure 5-31**.

5.1.2.5 Discussion

Based on the historical sampling data reviewed and discussed above, previous detections in the lakes are limited to one sample in Lake Waco (17.4 µg/L) that was considered to be an anomaly by the U.S. Navy, two samples in Lake Belton (4.1 µg/L and 7 µg/L) and two samples downstream of the Lake Belton dam (0.67 µg/L and 6 µg/L). These are the only five detections out of approximately 1,202 samples collected during these studies. If perchlorate were reaching the lakes, detections would most likely occur in the delta areas of these reservoirs as these areas receive direct discharge from the Bosque and Leon River watersheds and collect the greatest sediment deposition in each lake. The project team sampled these delta areas during this study and no perchlorate was detected in the delta area samples collected. In addition, no perchlorate was detected during ADCP transect sampling within Lake Belton or any of the water or irrigation intakes sampled within both the lakes. Based on the data collected by the U.S. Navy and the USACE project team, perchlorate detections have been limited to two random hits in Lake Belton, two hits downstream of the Lake Belton dam and one questionable detection in Lake Waco. Based on all of the non-detect results collected as part of the delta area, ADCP transect, and intake studies performed by the project team and the historical studies discussed, significant perchlorate concentrations are not consistently being detected within either of the lakes.



U.S. Army Corps of Engineers

Project:
BOSQUE AND LEON RIVER WATERSHEDS STUDY

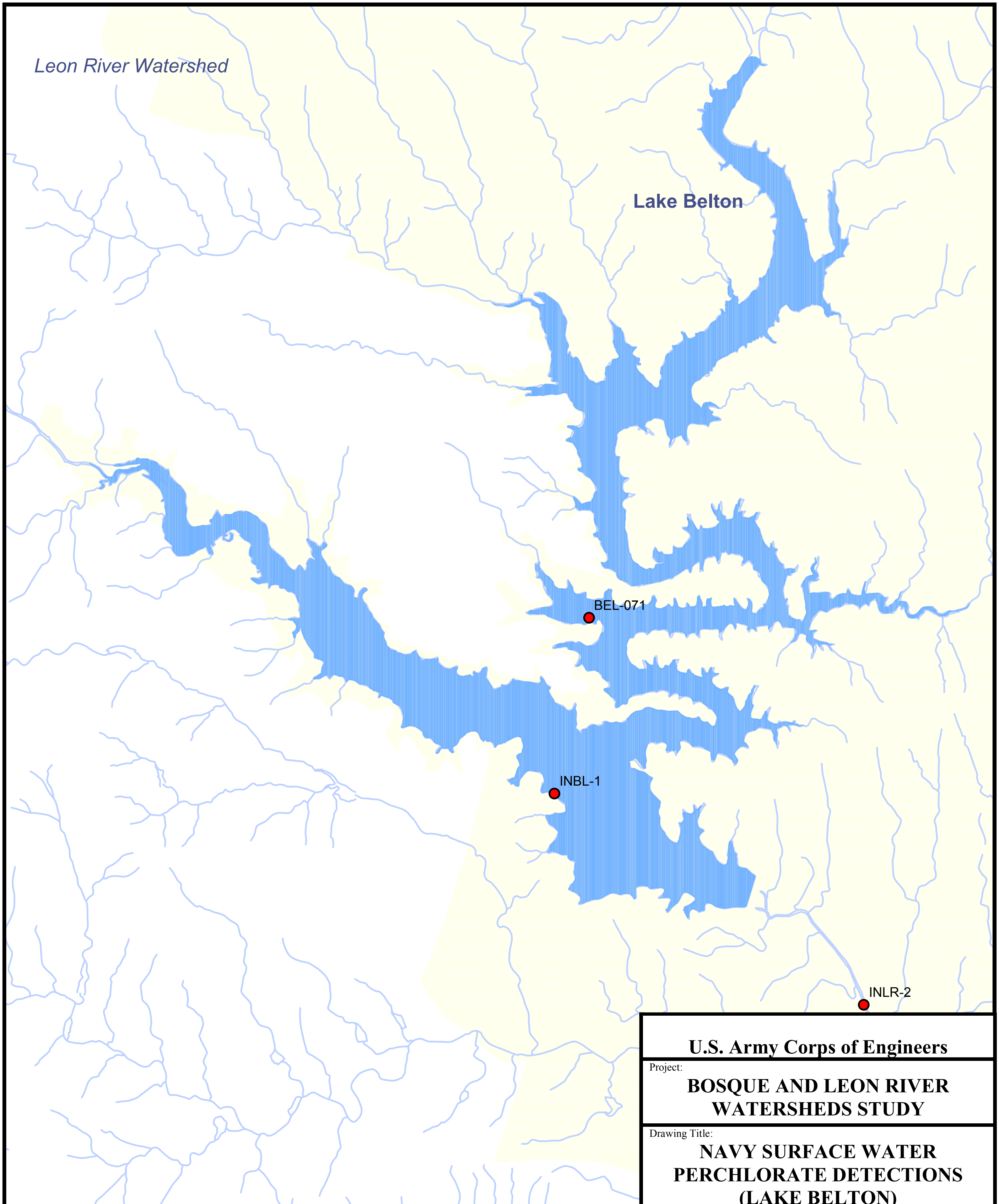
Drawing Title:
NAVY SURFACE WATER PERCHLORATE DETECTIONS (LAKE WACO)

Data from Navy Environmental Investigations (November 6, 2001)

Sheet 1 of 1 Sheets

SCALE: 1:57,672

FIGURE: 5-30



U.S. Army Corps of Engineers

Project:

BOSQUE AND LEON RIVER WATERSHEDS STUDY

Drawing Title:

NAVY SURFACE WATER PERCHLORATE DETECTIONS (LAKE BELTON)

Data from Navy Environmental Investigations (November 6, 2001)

Sheet 1 of 1 Sheets

SCALE: 1:104,937

FIGURE: 5-31

N

Legend

Study Area

Navy Surface Water Perchlorate Detections

0 0.5 1 Miles

5.1.3 Groundwater/Surface Water Interactions

5.1.3.1 Introduction

To assist in determining how perchlorate may move between groundwater and surface water, a groundwater/surface water interaction study was performed during this study. This portion of the Study was conducted as part of the Longitudinal Stream Sampling Study. All the methodologies and protocol followed are detailed in the *Final Longitudinal Stream Sampling Study Field Sampling Plan* (MWH, 2002b). Any deviations from the Field Sampling Plan are discussed further below.

5.1.3.2 Methodology

The methodology regarding the installation and setup of the automated sampling stations was previously discussed in detail in Section 5.1.1.2.2. Each station was equipped with an ISCO 4230 Flow Meter (equipped with a bubbler and a rain gauge) to monitor stream level and rainfall on a 15 minute basis. This study also included the installation of shallow groundwater monitoring wells near the surface water monitoring stations and installation of a water level pressure transducer into each well to monitor groundwater levels. Groundwater levels were also collected every fifteen minutes. Monitoring wells were constructed at eleven of the 15 automated sampling station locations, as listed in **Table 5-5**.

Table 5-5
Groundwater Monitoring Well Locations

Monitoring Station ID	Groundwater Monitoring Well Installed (Stations with a nearby well marked with an X)	Watershed
TRM1	X (shared well with station SC1)	Lake Belton
OC1	X	Lake Belton
SC1	X (shared well with station TRM1)	Lake Belton
SC3	X	Lake Belton
SC5	X	Lake Belton
LR1	X	Lake Belton
CHC1	No well installed	Lake Belton
SBR1	X	Lake Waco
SBR2	X	Lake Waco
SBR4	X	Lake Waco
HC1	X	Lake Waco
HC2	X	Lake Waco
SBR3	No well installed due to accessibility issues	Lake Waco
SBR5	X	Lake Waco
MBR1	No well installed due to accessibility issues	Lake Waco

The monitoring wells were located such that groundwater elevation measurements collected (in the shallow water-table aquifer) could be compared with the measurements collected at the nearby surface water monitoring stations. The resulting data were used to assess groundwater and surface water interactions and determine how groundwater levels were impacted by seasonal rainfall and storm events. Information on monitoring well construction and well completion data is included in **Appendix M**.

All completed monitoring wells were equipped with In-Situ, Inc. miniTROLL digital pressure transducers. The probes were ordered on a well-specific basis from In-Situ Inc. and cable lengths were pre-cut to fit the individual wells. The probes were installed into the wells to a depth of approximately 1-foot above bottom. This setting depth allows the probe to collect water readings even if water levels fall to near the bottom of the well, and allows the probe to be kept off of the well bottom where the pressure sensor may become surrounded by sediment. Probes do not need to be removed from the well to access data, as the support cable can be accessed at the surface with an interface cable. The pressure transducers were programmed to record the water level in the well every 15 minutes. This is the same data collection period as the Sampling Stations.

The data logger converts the pressure value sent by the transducer into feet of water above the transducer and records the values in its memory. The data were then downloaded from the logger to a PC computer using an RS-232 port. Each transducer had specific parameters that were input to the data logger to make the appropriate conversions from pressure units to feet of water. The field sampling team collected these data each time they mobilized to the sampling stations during scheduled sampling rounds.

5.1.3.3 Data

MWH performed a detailed, manual evaluation of the extensive data sets generated by the automated stream level and groundwater level equipment. These data evaluations were required prior to processing and analysis of the data to ensure the integrity of the data and conformance with the data quality objectives for the study.

Time Corrections

The time change between Standard Time (October 27, 2002) and Daylight Saving Time (April 6, 2003) for the sampling stations required data correction. Some stations were not reprogrammed immediately to reflect the time changes, which required the raw time data to be changed by an hour (back or forward depending on which time change) until the equipment was adjusted to record actual time. These corrections were documented with comments in the data spreadsheets.

Rainfall Data Corrections

Due to intermittent occurrences of equipment errors and dead batteries associated with the ISCO rainfall monitoring equipment, retrieved data had to be corrected to more closely reflect actual rainfall occurrences. To accomplish this task, accurate rainfall data from the closest possible sampling station were used to replace erred data. These occurrences were documented in the data spreadsheets and in the rainfall graphs that were generated and are as follows:

- For monitoring station CHC1, rainfall data from monitoring station LR1 were used from November 5, 2002 to March 24, 2003 due to equipment error.
- For monitoring station SC1, rainfall data from monitoring station SC3/OC1 rainfall data were used from August 18, 2003 to October 20, 2003 due to equipment error.
- For monitoring station TRM1, rainfall data from monitoring station SC3/OC1 rainfall data were used from August 18, 2003 to October 20, 2003 due to equipment error.

Monitoring station SBR5 was located under an overpass where rainfall could not be recorded. Consequently, rainfall data from the closest monitoring station, MBR1, were used to populate the rainfall data for monitoring station SBR5. The rainfall data were added to the monitoring station SBR5 data set because it was important to see trends in surface and ground water levels in conjunction with the rainfall events.

GW/SW Data Corrections

Due to intermittent occurrences of equipment errors, dead batteries, and high sediment levels accumulating on the strainer, the surface water levels and ground water levels retrieved were corrected to more closely reflect manual quality assurance and control levels taken at approximately two week intervals. Surface water levels at two monitoring stations, SBR3 and LR1, particularly toward the end of the sampling period, showed signs of high sedimentation that blocked the strainer and prevented reading surface water levels and retrieving storm samples. Some data from these two stations were discarded from the data set used for analysis, due to uncorrectable inaccuracies.

Based on the detailed review and evaluation of the extensive data generated by the surface water and groundwater level monitoring equipment, the vast majority of the collected data are of appropriate quality and were determined to be suitable for use in analysis of surface water and groundwater interactions. These data are all included in **Appendix N** and discussed below.

5.1.3.4 Discussion

One of the purposes of simultaneous monitoring of groundwater levels, stream levels, and rainfall at various locations throughout the study area was to obtain a more systematic understanding of watershed hydrology and the interrelationship of these three key components. As such, similar to the perchlorate concentration data from the monitoring stations, these data will be discussed in terms of stream segments, moving from upstream to downstream, as listed in **Table 5-6**:

Table 5-6
Longitudinal Monitoring Station Locations, by Stream Segment

STREAM SEGMENT	MONITORING STATIONS
NWIRP to Lake Belton, Leon River	
Station Creek above Tributary M	SC1
Station Creek between Tributary M and Onion Creek	SC3, TRM1
Station Creek below Onion Creek	SC5, OC1
Leon River below Station Creek	LR1
Fort Hood to Lake Belton	
Cowhouse Creek	CHC1
NWIRP to Lake Waco	
Harris Creek	HC1, HC2, SBR3
South Bosque River upstream of Harris Creek	SBR1, SBR2, SBR4
South Bosque River between Harris Creek and Middle Bosque River	SBR5
Middle Bosque River	MBR1

Plots of groundwater level, surface water level, and daily rainfall data from all stations are included in **Appendix N**.

5.1.3.4.1 NWIRP to Lake Belton

Station Creek Above Tributary M

The segment of Station Creek upstream of its confluence with Tributary M is characterized by monitoring station SC1. The stream level, groundwater level, and rainfall data are graphically depicted on the monitoring station SC1 plot included in **Appendix N**. The monitoring period time line spans the x-axis. Stream level and groundwater level are depicted on the left y-axis in feet mean sea level (fmsl). Rainfall is depicted on the right y-axis in inches of rainfall per day.

Stream levels at this location varied by approximately 7 feet during the monitoring period, ranging from dry (approximately 753.5 fmsl) to 760.5 fmsl. Rainfall amounts ranged from 0 to approximately 5.5 inches per day. Ten rainfall events exceeded 1.0 inch per day. Eight of these ten events coincide with stream level increases of at least two feet. These stream level increases are very short in duration, with the majority of the runoff peak from the rainfall event passing within 30 hours of the cessation of the event.

One of the other two events in excess of one inch per day coincides with a stream level increase of approximately 0.8 foot. The remaining rainfall event greater than one inch per day did not coincide with a stream level increase; rather, the stream remained dry during this event. A comparison of these rainfall data to those measured at nearby monitoring stations suggests that this rainfall event was localized. As a result, it is thought that rainfall from this event measured at monitoring station SC1 did not extend over a large enough area to generate significant runoff at this station. All significant stream level spikes observed at monitoring station SC1 appear to coincide with rainfall events.

Groundwater levels at monitoring station SC1 varied by approximately 3.5 feet during the monitoring period, ranging from approximately 756 to 759.5 fmsl. Groundwater level increases were generally sudden events, similar to stream level spikes. Conversely, groundwater level decreases occurred over a period of days or weeks, with the rate of drop decreasing with time. This is considered to be a classic response pattern in groundwater systems. All recorded groundwater level increases at this monitoring station coincided with recorded rainfall events. However, not all rainfall events resulted in groundwater level increases. As with stream level, this is likely a result of the very localized nature of some of the rainfall events.

Throughout the monitoring period, groundwater levels in the monitoring well were always higher than stream levels, suggesting that groundwater discharges to the stream. Therefore, this segment of the stream is characterized as a gaining stream.

Station Creek Between Tributary M and Onion Creek

The segment of Station Creek between tributary M and Onion Creek is characterized by monitoring stations TRM1 and SC3. The stream level, groundwater level, and rainfall data are graphically depicted on the plots for monitoring stations TRM1 and SC3 included in **Appendix N**. The monitoring period time line spans the x-axis. Stream level and groundwater level are depicted on the left y-axis in feet mean sea level (fmsl). Rainfall is depicted on the right y-axis in inches of rainfall per day.

Stream levels at monitoring station SC3 varied by approximately 4.5 feet during the monitoring period, ranging from dry (approximately 719.5 fmsl) to 724 fmsl. Rainfall ranged from 0 to approximately 1.4 inches per day. Eight rainfall events exceeded 1 inch per day. All of these six events coincide with stream level increases ranging from approximately 1 to 3 feet. As with the upstream segment of Station Creek, these stream level increases are very short in duration.

Stream levels at monitoring station TRM1 varied by approximately 5 feet during the monitoring period, ranging from dry (approximately 755.5 fmsl) to 760.5 fmsl. Rainfall ranged from 0 to 5.5 inches per day. Nine rainfall events exceeded 1 inch per day. Eight of these nine events coincide with stream level increases ranging from approximately 0.5 to 5 feet. As with the monitoring station SC3, these stream level increases are very short in duration.

The remaining rainfall event in excess of 1 inch per day did not coincide with a large stream level increase. The response to this event is not clearly discernable from other events that influence stream levels at this location.

Numerous stream level spikes that do not coincide with rainfall events were recorded at monitoring station TRM1. These stream level increases are believed to be a result of discharges of water in association with the U.S. Navy's remediation efforts at NWIRP. These events are particularly discernable on the plot for monitoring station TRM1 (**Appendix N**) during the period of February through May 2002. While more muted, these same patterns are discernable in stream levels at the downstream monitoring station SC3.

Groundwater levels at monitoring station TRM1 varied by approximately 3.5 feet during the monitoring period, ranging from approximately 756 to 759.5 fmsl. This monitoring well is shared between monitoring station SC1 and TRM1. Groundwater level increases were generally sudden events, similar to stream level spikes. Conversely, groundwater level decreases occurred over a period of days or weeks, with the rate of drop decreasing with time. This is considered to be a classic response pattern in groundwater systems. All recorded groundwater level increases at this monitoring station coincided with recorded rainfall events. However, not all rainfall events resulted in groundwater level increases. As with stream level, this is likely a result of the very localized nature of some of the rainfall events.

Groundwater levels at monitoring station SC3 varied by approximately 8 feet, ranging from approximately 717 to 725 fmsl. While the larger increases in groundwater levels were sudden and coincident with rainfall, a pattern of smaller increases, on the order of a few tenths of a foot, was clearly observable in this monitoring well. In addition to a difference in magnitude, these fluctuations occur over a more extended period of time. The resultant shape of the hydrograph from these events is a hump rather than a spike, as seen during the month of April 2002 on the plot for monitoring station SC3 (**Appendix N**). These groundwater level humps at monitoring station SC3 coincide with the non-rainfall related stream level increases recorded at monitoring station TRM1.

At monitoring station TRM1, groundwater levels in the monitoring well were higher than stream levels, except during several of the peaks associated with the water level increases attributed to NWIRP discharges. During these discharge events, Tributary M appears to transition from a gaining stream to a losing stream, with surface water flowing into the groundwater system during these discharge events. The effect of this groundwater recharge is reflected in increases in groundwater levels at the downstream monitoring station SC3. Relative to stream level, groundwater levels at monitoring station SC3 vary from above to below stream, depending on the frequency and duration of rainfall events. Therefore, this segment of the stream is characterized as transitional between a gaining stream and losing stream, depending on both stream flow and rainfall.

Station Creek Below Onion Creek

The segment of Station Creek below Onion Creek is characterized by monitoring stations OC1 and SC5. The stream level, groundwater level, and rainfall data are graphically depicted on the plots for monitoring stations OC1 and SC5 included in **Appendix N**. The monitoring period time line spans the x-axis. Stream level and groundwater level are depicted on the left y-axis in feet mean sea level (fmsl). Rainfall is depicted on the right y-axis in inches of rainfall per day.

Stream levels at monitoring station SC5 varied by nearly 16 feet during the monitoring period, ranging from dry (602.5 fmsl) to just over 618 fmsl. Rainfall ranged from 0 to nearly 3 inches per day. Six rainfall events exceeded 1 inch per day. Five of these six events coincide with stream level increases of at least two feet. These stream level increases are very short in duration, with the majority of the runoff peak from the rainfall event passing within 72 hours of the cessation of the event. The remaining rainfall event in excess of 1 inch per day coincided with a much smaller stream level increase.

Four stream spikes at monitoring station SC5 do not coincide with large rainfall events recorded at this same monitoring station. However, rainfall data from upstream monitoring stations suggest that this stream water level peak was, in fact, a result of rainfall runoff. This rainfall event appears to have been localized to the extent that only minor rainfall was recorded at monitoring station SC5 despite the measurement of the stream level increase.

Stream levels at monitoring station OC1 varied by approximately 4.5 feet during the monitoring period, ranging from dry (707.5 fmsl) to 712 fmsl. Rainfall ranged from 0 to approximately 5.5 inches per day. Twelve rainfall events exceeded 1 inch per hour. Nine of these twelve events coincide with stream level increases of at least one foot. These stream level increases are very short in duration, with the majority of the runoff peak from the rainfall event passing within 48 hours of the cessation of the event. It is presumed that the remaining three rainfall events in excess of 1 inch per day were either not of sufficient duration or did not extend over a large enough area to generate sufficient runoff to measurably increase water levels at this location.

Groundwater levels at monitoring station SC5 varied by over 11 feet during the monitoring period, ranging from approximately 602.5 to 614 fmsl. Groundwater level increases were generally sudden events, similar to stream level spikes. Conversely, groundwater level decreases occurred over a period of days or weeks, with the rate of drop decreasing with time. This is considered to be a classic response pattern in groundwater systems. All groundwater level increases at this monitoring station in excess of a few tenths of a foot coincided with recorded rainfall events. However, as observed at other monitoring stations, not all rainfall events resulted in groundwater level increases.

With the exception of late summer 2002, groundwater levels in the monitoring well were always higher than stream levels, suggesting that groundwater discharges to the stream. However, during the late summer, groundwater levels dropped below stream levels, indicating this segment of the stream to be transitional with respect to gaining and losing conditions, like the preceding stream segment.

Groundwater levels at monitoring station OC1 varied by approximately 8 feet during the monitoring period, ranging from approximately 702 to 710 fmsl. Groundwater level increases on the order of 1 foot were coincident with rainfall events and generally sudden, as observed at other locations. However, an extensive number of hump-shaped water level fluctuations, on the order of a few tenths of a foot, were recorded. The peaks and troughs of these fluctuations are coincident with those recorded at monitoring station SC3 and attributed to discharges from NWIRP. However, no discharges from NWIRP are known to occur in Onion Creek. Groundwater levels at monitoring station OC1 are consistently lower than the stream levels, indicating that this segment of Onion Creek is a losing stream.

Leon River Below Station Creek

The segment of the Leon River below Station Creek is characterized by monitoring station LR1. The stream level, groundwater level, and rainfall data are graphically depicted on the plot for monitoring station LR1 included in **Appendix N**. The monitoring period time line spans the x-axis. Stream level and groundwater level are depicted on the left y-axis in feet mean sea level (fmsl). Rainfall is depicted on the right y-axis in inches of rainfall per day.

Stream levels at this location varied by approximately 18 feet during the monitoring period, ranging from 594 to 611 fmsl. Rainfall amounts ranged from 0 to over 2.4 inches per day. Nine rainfall events exceeded 1 inch per day. Five of these nine events appear coincident with stream level increases from approximately two to twelve feet. These stream level increases are somewhat longer in duration than those observed farther upstream in the watershed, with the majority of the runoff peak from the rainfall event passing within 10 days of the cessation of the event.

The remaining rainfall events in excess of 1 inch per day did not coincide with large stream level increases; rather, the observed stream level increases were on the order of a few tenths of a foot to one foot. It is presumed that this rainfall event was either not of sufficient duration or did not extend over a large enough area to generate sufficient runoff to measurable increase water levels at this location.

Contrary to the high coincidence of rainfall with stream level increases, very few stream level increases were coincident with rainfall. In fact, particularly during the summer months of 2003, daily variations in stream level at monitoring station LR1 are typical. This indicates that the stream flow characteristics at this location are dominated by management actions, such as releases for irrigation, on the Leon River upstream of Station Creek. Given the importance of the Leon River to the region's water supply, this result is expected.

Groundwater levels at monitoring station LR1 varied by nearly ten feet during the monitoring period, ranging from approximately 592 to over 601 fmsl. Groundwater level increases were generally sudden events, similar to stream level spikes. Conversely, groundwater level decreases occurred over a period of weeks, with the rate of drop decreasing with time. This is considered to be a classic response pattern in groundwater systems. All recorded groundwater level increases at this monitoring station coincided with recorded rainfall events. However, not all rainfall events resulted in groundwater level increases. As with stream level, this is likely a result of the very localized nature of some of the rainfall events.

Throughout the monitoring period, groundwater levels in the monitoring well were always lower than stream levels, suggesting that this segment of the Leon River is a losing stream. However, there does not appear to be an appreciable response of groundwater level to the stream level fluctuations that dominate the Leon River during the summer months. As a result, the connection between the stream and groundwater systems at this location appears to be weak.

5.1.3.4.2 Cowhouse Creek

The entire drainage area of Cowhouse Creek tributary to Lake Belton is characterized by monitoring station CHC1. The stream level and rainfall data are graphically depicted on the plot for monitoring station CHC1 included in **Appendix N**. No groundwater level data were obtained. The monitoring period time line spans the x-axis. Stream level is depicted on the left y-axis in feet mean sea level (fmsl). Rainfall is depicted on the right y-axis in inches of rainfall per day.

Stream levels at this location varied by approximately 6 feet during the monitoring period, ranging from approximately 574.5 to 580.5 fmsl. Rainfall ranged from 0 to 2.43 inches per day. Fourteen rainfall events were 1 inch per day or greater. Six of these fourteen events coincide with stream level increases of approximately 1 foot or more. These stream level increases are relatively long in duration, with the majority of the runoff peak from the rainfall event passing within 2 weeks of the cessation of the event. The remaining eight rainfall events in excess of 1 inch per day did not coincide with large stream level increases; rather, the observed stream level increases were either smaller or not discernable from other stream level variations.

5.1.3.4.3 NWIRP to Lake Waco

Harris Creek

The segment of Harris Creek upstream of its confluence with the South Bosque River is characterized by monitoring stations HC1, HC2, and SBR3. The stream level, groundwater level, and rainfall data are graphically depicted on the plots for monitoring stations HC1, HC2, and SBR3 included in **Appendix N**. The monitoring period time line spans the x-axis. Stream level and groundwater level are depicted on the left y-axis in feet mean sea level (fmsl). Rainfall is depicted on the right y-axis in inches of rainfall per day.

Stream levels at monitoring station HC1 varied by approximately 4 feet during the monitoring period, ranging from 664.5 to 668.5 fmsl. Rainfall ranged from 0 to 1.75 inches per day. Five rainfall events exceeded 1 inch per day. All five of these events coincide with stream level increases ranging from approximately 1 to 3 feet. As with the streams from NWIRP to Lake Belton, these stream level increases are very short in duration.

Stream levels at monitoring station HC2 varied by approximately 12 feet during the monitoring period, ranging from 593 fmsl to approximately 605 fmsl. Rainfall ranged from 0 to slightly over 3.5 inches per day. Eleven rainfall events exceeded 1 inch per day. All but three of these events coincide with stream level increases ranging from approximately 1.5 to 11 feet. As with other monitoring stations, these stream level increases are very short in duration. Three rainfall events in excess of 1 inch per day resulted in smaller stream level increases of only a few tenths of a foot. This is likely a result of the localized nature and/or short duration of rainfall events in the study area.

Stream levels at monitoring station SBR3 varied by approximately 8 feet during the monitoring period, ranging from approximately 492 to 500 fmsl. Rainfall ranged from 0 to 1.9 inches per day. Ten rainfall events exceeded 1 inch per day. Due to high sedimentation, the stream level data set for this monitoring station is incomplete. Where data are available, all rainfall events in excess of 1 inch per day coincide with stream level increases of at least 0.5 feet. As with other monitoring stations, these stream level increases are very short in duration.

Groundwater levels at monitoring station HC1 varied by over 5 feet during the monitoring period, ranging from approximately 663 to 668 fmsl. Groundwater level increases in excess of a few tenths of a foot were generally sudden events, similar to stream level spikes. Conversely, groundwater level decreases occurred over a period of days or weeks, with the rate of drop decreasing with time. This is considered to be a classic response pattern in groundwater systems. Six groundwater level increase events in excess of 1 foot were recorded at this monitoring station. Of these, only two clearly coincided with a recorded rainfall event in excess of 1 inch per day. Rainfall records from the nearby monitoring station HC2 indicate rainfall events that were coincident with the other four groundwater level rises. This indicates the localized nature of some of the rainfall events and is consistent with findings from monitoring stations on the NWIRP to Lake Belton tributary system.

Beginning in mid to late June 2003, groundwater levels at monitoring station HC1 exhibit a daily pattern of peaks and troughs with a total daily variation of a few tenths of a foot. The peaks typically occur near 10 AM and the troughs near 5 PM. This water level variation may be attributable to operation of a nearby well for irrigation purposes. Plant transpiration is not a likely cause given the timing of the peaks and troughs.

Groundwater levels at monitoring station HC2 varied from 570 to 602 fmsl. However, the pattern of groundwater level variation in this monitoring well is very different from all other monitoring stations, gradually rising until early April 2003 and then gradually decreasing throughout the remainder of the monitoring period. The only exception to this is a sudden increase of approximately 5 feet that appears to coincide with a rainfall event on October 9, 2003. These data suggest that the groundwater system at this location is largely disconnected from the surface hydrology dynamics. A review of the well log for this monitoring well indicates that earth materials at this location were very dense, unfractured, and that water was not encountered during borehole drilling.

Groundwater levels at monitoring station SBR3 varied from approximately 494 to 498 fmsl. The pattern of groundwater level variation was typical of that observed at other monitoring stations. Strong coincidence of groundwater level increases to rainfall events was recorded.

Groundwater levels at monitoring station HC1 are variable relative to stream level, suggesting that the stream is transitory between gaining and losing conditions. At monitoring station SBR3, groundwater levels are consistently higher than stream levels, suggesting gaining stream conditions at this location.

South Bosque River Upstream of Harris Creek
The segment of the South Bosque River upstream of its confluence with Harris Creek is characterized by monitoring stations SBR1, SBR2, and SBR4. The stream level, groundwater level, and rainfall data are graphically depicted on the plots for monitoring stations SBR1, SBR2, and SBR4 included in **Appendix N**. The monitoring period time line spans the x-axis. Stream level and groundwater level are depicted on the left y-axis in feet mean sea level (fmsl). Rainfall is depicted on the right y-axis in inches of rainfall per day.

Stream levels at monitoring station SBR1 varied by approximately 3.5 feet during the monitoring period, ranging from 607 to 610.5 fmsl. Rainfall ranged from 0 to 1.88 inches per day. Nine rainfall events exceeded 1 inch per day. Only four of these nine events coincide with stream level increases of approximately 1 foot or more. Based on review of rainfall data from nearby monitoring stations, the other five rainfall events of this magnitude were very localized and/or of short duration, thus significant surface runoff did not result.

Stream levels at monitoring station SBR2 varied by approximately 12 feet during the monitoring period, ranging from approximately 530 fmsl to 542 fmsl. Rainfall ranged from 0 to just over 1.4 inches per 15 day. The stream level data are characterized by a preponderance of one- to three-foot rapid variations in water levels during the period from December 2002 through April 2003. These variations are unique in both frequency and magnitude and are not coincident with rainfall or other known surface hydrologic events.

Stream levels at monitoring station SBR4 varied by approximately 12 feet during the monitoring period, ranging from approximately 501 to 513 fmsl. Rainfall ranged from 0 to just over 1.5 inches per day. Ten rainfall events exceeded one inch per day. Each of these rainfall events coincides with stream level increases of at approximately 0.5 feet or more. As with other monitoring stations, these stream level increases are very short in duration. The unique stream level fluctuations recorded at the upstream monitoring station SBR2 are not observable at monitoring station SBR4.

Groundwater levels at monitoring station SBR1 varied by nearly 5 feet during the monitoring period, ranging from approximately 608 to 613 fmsl. Groundwater level increases in excess of a few tenths of a foot were generally sudden events, similar to stream level spikes. Conversely, groundwater level decreases occurred over a period of days or weeks, with the rate of drop decreasing with time. This is considered to be a classic response pattern in groundwater systems. Six groundwater level increase events in excess of 0.5 feet were recorded at this monitoring station. Each of these coincided with a recorded rainfall event.

Groundwater levels at monitoring station SBR2 varied from 529 to 532 fmsl. However, the pattern of groundwater level variation in this monitoring well is dissimilar from the monitoring wells at upstream locations. The pattern of water level exhibited on the plot for monitoring station SBR2 (**Appendix N**) is hump-shaped rather than spiky, and looks very much like that observed at monitoring stations SC3 and OC1. At these other two locations, the hump-shaped pattern was attributed to groundwater recharge from surface water discharge events at NWIRP. Similarly, the pattern of groundwater level change at monitoring station SBR2 is suggestive of groundwater recharge from the apparent surface water discharges recorded at this monitoring station.

No groundwater monitoring wells were installed at monitoring station SBR-4.

Groundwater levels at monitoring station SBR1 are consistently higher than stream levels, suggesting that this location is in a gaining stream condition. Groundwater levels at monitoring station SBR2 are typically lower or only slightly higher than stream water levels, suggesting this location to typically function as a losing stream.

South Bosque River Between Harris Creek and Middle Bosque River

The segment of the South Bosque River downstream of the confluence with Harris Creek and upstream of the confluence with the Middle Bosque River is characterized by monitoring station SBR5. The stream level, groundwater level, and rainfall data are graphically depicted on the plot for monitoring station SBR5 included in **Appendix N**. The monitoring period time line spans the x-axis. Stream level and groundwater level are depicted on the left y-axis in feet mean sea level (fmsl). Rainfall is depicted on the right y-axis in inches of rainfall per day.

Stream levels at monitoring station SBR5 varied by approximately 10 feet during the monitoring period, ranging from 453 to 463 fmsl. Rainfall ranged from 0 to approximately 1.7 inches per day. Eight rainfall events exceeded 1 inch per day. Each of these events coincides with stream level increases of approximately 0.5 feet or more. As with other monitoring stations, these stream level increases are very short in duration.

Groundwater levels at monitoring station SBR5 varied by nearly 10 feet during the monitoring period, ranging from approximately 453 to 463 fmsl. Groundwater level increases in excess of a few tenths of a foot were generally sudden events, similar to stream level spikes. Smaller groundwater level variations of a few tenths of a foot during the January through April 2003 period were characteristically hump-shaped, similar to those observed at the upstream monitoring station SBR2. In fact, these variations appear to coincident with or perhaps slightly lagging those at monitoring station SBR2.

Groundwater levels at monitoring station SBR5 are typically higher than stream levels, suggesting that this location is in a gaining stream condition.

Middle Bosque River downstream of the South Bosque River
The Middle Bosque River downstream of the confluence with the South Bosque River and upstream of Lake Waco is characterized by monitoring station MBR1. The stream level and rainfall data are graphically depicted on the plot for monitoring station MBR1 included in **Appendix N**. No groundwater level data were obtained. The monitoring period time line spans the x-axis. Stream level is depicted on the left y-axis in feet mean sea level (fmsl). Rainfall is depicted on the right y-axis in inches of rainfall per day.

Stream levels at this location varied by approximately 5 feet during the monitoring period, ranging from 445 to 450 fmsl. Rainfall ranged from 0 to over 1.7 inches per day. Six rainfall events exceeded 1 inch per day. There is not a clear response to 1-hour rainfall at this station, possibly because this location is far downstream in the watershed and is reported to be in the backwater of Lake Waco.

5.1.4 Flow

Streamflows at most of the 15 longitudinal sampling stations were estimated throughout the duration of the sampling to determine how any potential perchlorate detections might impact Lakes Belton and Waco. In addition to flows at each of the stations, acoustic doppler technology was used to characterize potential preferential flow paths through Lake Belton. A detailed discussion of the ADCP flow study is provided in Section 5.1.4.2.

5.1.4.1 Streams

5.1.4.1.1 Introduction

The amount of flow reaching Lakes Belton and Waco from the NWIRP property compared to flows reaching these lakes from other watershed areas is critical both in estimating the potential impact of perchlorate concentrations detected in the streams and in assessing the potential for water supply contamination from the NWIRP source. Flow data from two flow surveys were used in conjunction with the surface water level data described in Section 5.1.3.3 to estimate flows. Where available, flow data from the U.S. Navy Environmental Investigations, the USGS, and ADCP studies performed in the Leon River just upstream of Lake Belton were used to corroborate the estimated flows.

5.1.4.1.2 Methodology

TIAER surveyed the stream channel cross-section and centerline longitudinal profile at each of the stream monitoring locations. They also attempted to measure the flow at each station in March, 2003. BRA conducted a second flow measurement study at each station in October, 2003. Flows over the duration of the one-year monitoring period were then estimated using water level data, channel geometry data and Manning's flow equation.

This section documents the methodologies used in measuring and calculating stream flows. All associated data, including stream channel survey data, are presented in Section 5.1.4.1.3.

5.1.4.1.2.1 Stream Channel Survey

TIAER surveyed the stream channel at each monitoring station location to determine the appropriate stream cross-section and slope characteristics needed to estimate actual stream flows. The survey included:

- Establishing a benchmark.
- Measuring elevations across the floor of the stream channel (perpendicular to flow) to establish the stream channel cross-section.
- Measuring elevations along the floor of the stream channel (parallel to flow) to determine the slope.
- Measuring the elevation of the bubbler, top of stream, and bottom of stream at the bubbler location.

The results from this survey are included in **Appendix O**.

5.1.4.1.2.2 Measured Stream Flow

Flow at or near most of the stations was measured twice during this study, once by TIAER in March 2003 and once by BRA in October 2003. Flow could not be measured at stations SBR5, MBR1, or CHC1. Sites MBR1 and CHC1 were reported to be in the backwater of Lakes Waco and Belton, respectively. Flow at SBR5 may also be affected by backwater from Lake Waco; flow at this site was very slow and could not be measured during the flow survey.

Per standard methodology, velocity was measured at 60% of the flow depth. Both velocity and depth of flow were measured at several points across the stream cross-section. The measured velocity, depth, and width of each sub-section were used to compute the volumetric flow across each sub-section, which was then summed to determine the total flow at that point in the stream.

The depth of flow recorded by the water level meter during the first flow survey was noted in order to relate the water level data to the measured flows. The second flow survey followed a large storm that washed away, broke, or submerged the water level meters at all of the stations except CHC1 and OC1 . Therefore, depths of flow reported at water level meters during this second survey are approximate and must be used with caution.

5.1.4.1.2.3 Flow Calculations

Ideally, the flow surveys could have been used to determine a level-discharge relationship to provide flow data from the level data collected over the course of this study. However, a valid level-flow relationship could not be determined based on the available flow data from the two surveys previously discussed. Several of the water levels reported during the second flow survey were very close to levels reported during the first survey with respect to the range of levels seen over the course of the study. Additionally, levels reported during the second survey can only be considered approximate, as most of the water level meters had been washed away. Therefore, the project team chose to estimate flows at each station using Manning's equation, which predicts flow under uniform flow conditions, where Q = flow in cfs, A = cross-sectional area of flow, R = hydraulic radius, S = slope, and n = Manning roughness coefficient:

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2}$$

Although flow in these streams is not uniform, the Manning equation can still result in reasonable estimates of stream flow if n values are carefully chosen and results are compared to actual flow data.

Channel Geometry

The channel geometry parameters necessary for use of the Manning equation were calculated using CGAP 3.5, a publicly available software program developed by the USGS. The area of flow, wetted perimeter, and hydraulic radius were calculated for each stream cross-section over the range of water levels observed at each station at intervals ranging from 0.03 foot to 0.10 foot. Channel geometries at water levels between those calculated by the USGS program were then interpolated. At several stations, the highest measured water level was above the extent of the surveyed cross-section. In these cases, the program extrapolated the cross section to the necessary level.

Channel slope at each station was determined by a longitudinal stream centerline survey over 400 feet of the channel length near the station. In a few cases, the survey crew reported a slight negative slope. While a slight negative slope can be valid in some sections of a natural channel, use of the Manning equation requires a positive slope. In these cases, a slight positive slope was estimated by looking at points along the longitudinal survey other than the end points.

Photos of well-studied river channels with known Manning's n values, as well as tabulated values, were used to make initial estimates of the channel n value to use at each site. These initial estimates were refined by comparing the resulting depth-flow relationship to both flow surveys.

Several of the stream channel cross-sections show a defined main channel with distinct floodplains. Such compound channels often have very different roughness coefficients (n values) in the main channel than on the floodplains. Two n values were estimated at stations with this type of cross section, and a compound roughness coefficient was used when the depth of flow exceeded the flood plain level. This compound roughness coefficient was calculated by scaling the two n values based on the wetted perimeter associated with each n value, according to the following equation, where n_c is the composite roughness coefficient and P is the wetted perimeter:

$$n_c = \left(\frac{\sum P_i (n_i)^{3/2}}{\sum P_i} \right)^{2/3}$$

Verification

Calculated flows in the Leon River were compared not only to the two flow surveys performed at the site, but also to flows measured during two ADCP studies downstream of station LR1 on the Leon River. USGS data at an upstream station near Gatesville provided additional verification that the flows calculated for the Leon River were reasonable. Flows at stations SC1, TRM1, and HC1 were compared to flow data previously collected by the U.S. Navy at nearby locations to ensure that calculated flows were within a reasonable range.

5.1.4.1.3 Data

Data collected during the stream channel survey, both flow surveys, and the resulting calculated flows over the duration of monitoring are presented in this section. These data are organized by watershed, with the Leon River watershed data presented first and the Bosque River watershed data presented second. Although flows were not calculated at Cowhouse Creek, stream channel survey data at monitoring station CHC1 are presented following the Bosque River watershed data.

5.1.4.1.3.1 Leon River Watershed

The NWIRP to Lake Belton portion of the Leon River Watershed studied during this investigation includes Tributary M, Onion Creek, Station Creek, and the Leon River downstream of Station Creek.

Leon River Watershed Measured Data

Appendix O includes photographs of each stream monitoring location, plots of the surveyed cross-section, plots of the surveyed longitudinal centerline profile, and three-dimensional cross-section representations of the stream channel.

Table 5-7 summarizes the results of the two flow surveys at each station in the Leon River Watershed, including date, time, depth of stream at the bubbler location, and measured flow. As discussed previously, the second flow survey was completed following flooding that washed away all sampling equipment. Therefore, depths at the bubbler reported during the second flow survey may or may not be comparable to depths reported during the first flow survey. The flow measurements are less sensitive to the exact measurement locations, and therefore can be considered accurate for both surveys.

Table 5-7
NWIRP to Lake Belton Flow Survey Results

Monitoring Station ID	Flow Survey 1			Flow Survey 2		
	Date/Time	Depth at Bubbler (ft)	Flow (cfs)	Date/Time	Depth at Bubbler (ft)	Flow (cfs)
TRM1	3/4/03 18:55	0.90	2.84	10/16/03 10:05	1.20	0.52
OC1	3/5/03 10:45	0.40	4.46	10/16/03 10:30	0.80	0.51
SC1	3/4/03 18:25	0.83	10.42	10/16/03 9:45	1.30	0.84
SC3	3/5/03 09:30	1.73	16.38	10/16/03 9:15	1.15	3.56
SC5	3/5/03 12:45	0.65	38.03	10/16/03 11:10	1.20	5.91
LR1	3/25/03 11:30	3.00	189.34	11/6/03 9:15	2.70	102.33

Leon River Watershed Flow Calculations.
As discussed in the methodology section, flows were estimated over the duration of monitoring based on measured water level, channel geometry determined during surveying, and the Manning equation for uniform flow. Use of the Manning equation requires that a roughness coefficient, Manning's n, be estimated. **Table 5-8** summarizes the Manning's n values used at each station, including comments on why these values were chosen.

Table 5-8
NWIRP to Lake Belton Manning's n Values

Station ID	Manning's n		Comments
	Main Channel	Flood Plain	
TRM1	0.30	0.03	Small, meandering channel. Grassy floodplain.
OC1	0.11	0.25	Thickly vegetated floodplain.
SC1	0.11	0.035	Weedy, meandering main channel. Grassy floodplain.
SC3	0.50	NA	Very high value used for main channel to correct for unusual flow conditions at this station. Stagnant water at the bubbler location has frequently been observed, which would cause on overestimation of flow. Additionally, this site is upstream of a debris screen, which could cause depths greater than the normal uniform flow depth.
SC5	0.06	0.035	Relatively straight channel section.
LR1	0.09	0.03	Relatively straight channel section.

With the exception of station SC3, the n values used typically decrease as channel size increases. This trend is as expected, since roughness, changes in cross-section, or channel meanders will have a much more significant effect on very small channels than on larger ones. With the exception of station OC1, which has a thickly vegetated floodplain (see the photo in **Appendix O**), this watershed is characterized by grassy floodplains that have fairly low roughness coefficients.

Plots of the resulting calculated flows over the monitoring duration are included in **Appendix P**. The two manual flow measurements taken at each monitoring station are also shown on these plots. **Figure 5-32** shows flows from each monitoring station from upstream on Station Creek and Tributary M down to monitoring station SC5 plotted on the same graph for comparison.

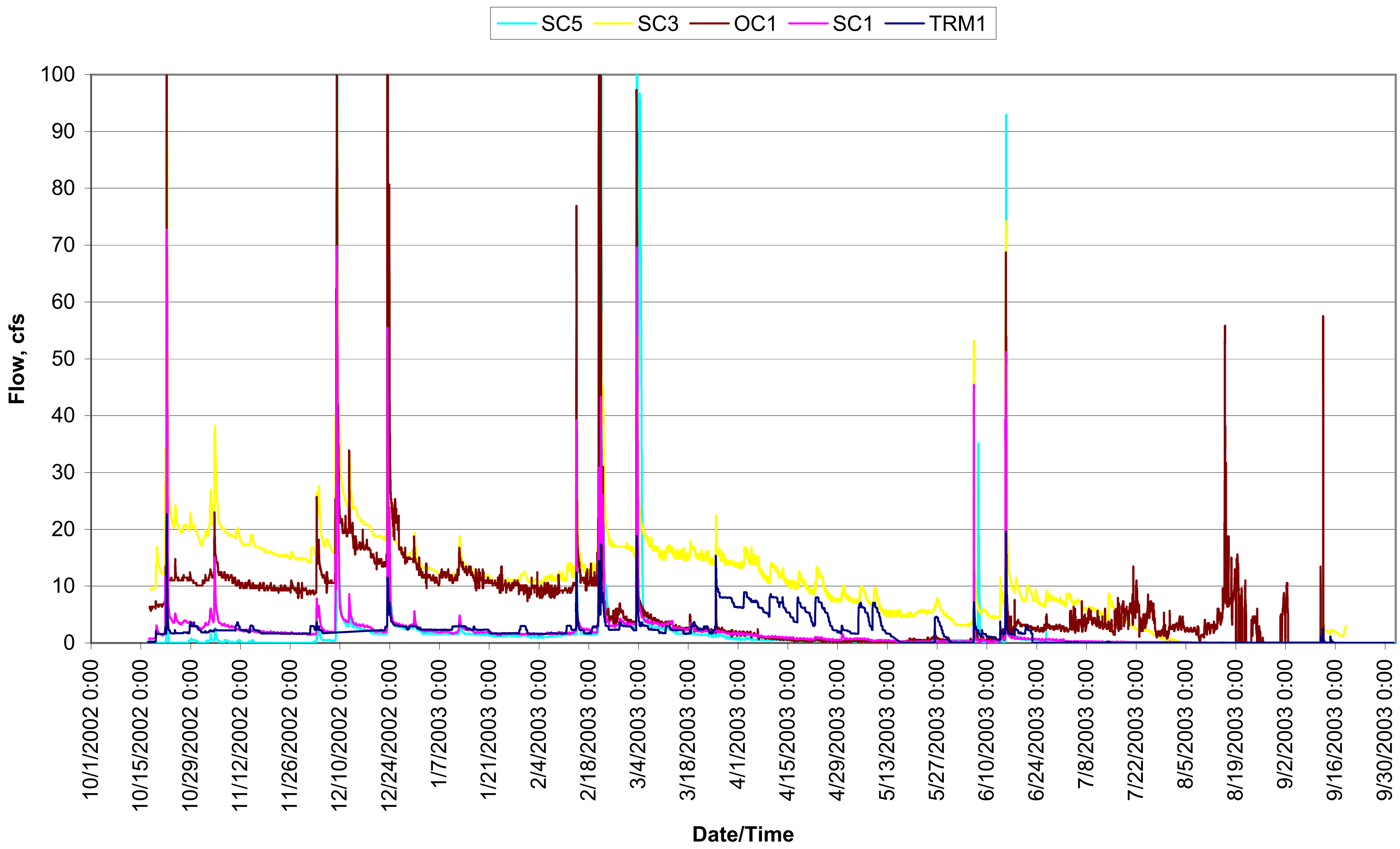
Verification of Calculated Flows

Calculated flows in the Leon River Watershed were compared against flow measurements and estimates from other sources to verify that flows were within a reasonable range. These other flow data included: manual flow measurements performed at each stream during this study; two flow measurements performed during the ADCP study at the Leon River, 6 miles downstream from monitoring station LR1; current USGS flow data from the Leon River near Gatesville, approximately 35 miles upstream from monitoring station LR1; and previous U.S. Navy flow data at sites just upstream of monitoring stations SC1 and TRM1.

<u>Manual Flow Measurements.</u> Two manual flow surveys were completed during this study at each monitoring station not affected by backwater from the lakes. These manual flow measurements were plotted on the flow data graphs included in **Appendix P**. However, because the second flow survey was completed after several of the water level meters had been washed away by a high rainfall event, flow measured during this second survey could not be compared directly to a calculated flow at several stations. Additionally, at stations where level data were available during the second flow survey, measured flows could not be correlated for both flow surveys with flows estimated using Manning's flow equation. Therefore, the depth-discharge curve for each station based on the calculated flows was plotted and compared to the flows and depths reported during the two flow surveys. As seen on these graphs, also included in **Appendix P**, the calculated depth-flow curve generally falls between the two manual flow survey points.

<u>Leon River ADCP Measurements.</u> Two additional flow measurements using ADCP technology were performed at the Leon River during the ADCP portion of this study. These measurements were made approximately 6 miles downstream from monitoring station LR1. These additional two points are plotted with the flow data for monitoring station LR1 and on the depth-discharge curve described above, both included in **Appendix P**. The depth used in plotting these points was that measured at the bubbler at LR1 at the time the ADCP measurement was taken.

Figure 5-32
Comparison of Flows at Monitoring Stations Upstream of the Leon River



Leon River USGS Data. A USGS station exists on the Leon River near Gatesville, approximately 35 miles upstream of monitoring station LR1. Flows reported at this USGS station during the manual flow surveys and ADCP measurements were approximately half of the measured flow at monitoring station LR1. Flows at monitoring station LR1 and the USGS station were compared throughout the study to ensure that calculated flows at much higher stages than those at which the flow measurements were taken were reasonable.

U.S. Navy Data. The U.S. Navy collected data from several streams at or near the NWIRP site between March and May 2000. One location was approximately 0.4 mile upstream of monitoring station SC1, and one was approximately 0.6 mile upstream of monitoring station TRM1. Although the U.S. Navy data were reported for a different period than flows calculated for this study, these data could still be used to verify the general range of flow calculated during this study. **Table 5-9** summarizes the U.S. Navy flows reported near these two stations compared to flows calculated during this study.

Table 5-9
Comparison of Monitoring Station TRM1 and SC1 Flows to U.S. Navy Data

Station ID	Dates	Typical Range in Dry Weather Flow (cfs)	Typical Range in Peak Storm Water Flow* (cfs)
TRM1	October 2002 through October 2003	0 – 2	8 – 15 during typical storms, with a peak flow of approximately 75 cfs during October 2003 storm.
0.6 mile Upstream of TRM1 (U.S. Navy Data)	March 2000 through May 2000	0 – 0.2	Almost no response, with most spikes < 10 cfs. One spike of 115 cfs
SC1	October 2002 through October 2003	0 – 3	10 – 70 during typical storms, with a peak flow of approximately 700 cfs during October 2003 storm.
0.4 mile Upstream of SC1 (U.S. Navy Data)	March 2000 through May 2000	0 – 1.5	20 - 270

Discussion of Leon River Watershed Monitoring Stations
The pattern of the calculated flow at each of these stations mimics that of the recorded water levels: low values during dry periods and rapid, sharp spikes following significant rainfall events. This pattern was described in detail in Section 5.1.3 for each stations; therefore, a detailed description of the response to rainfall events is not repeated here. **Table 5-10** summarizes the typical dry weather and storm flows estimated for each site.

Table 5-10
Leon River Watershed, Typical Flows

Station ID	Typical Range in Dry Weather Flow (cfs)	Typical Range in Peak Storm Water Flow* (cfs)	Comments
TRM1	0 – 2	8 – 15	Peak flow of approximately 75 cfs during October 2003 storm.
OC1	0.2 – 10	60 – 130	Peak flow of approximately 400 cfs during October 2003 storm.
SC1	0 – 3	10 – 70	Peak flow of approximately 700 cfs during October 2003 storm.
SC3	0 – 15	30 – 100	Level data during October 2003 storm not available.
SC5	0 – 2	40 – 230	Peak flow of nearly 6,000 cfs during October 2003 storm.
LR1	100 – 300	500 – 2,000	Level data during October 2003 storm not available. Flow at an upstream USGS station on the Leon River near Gatesville peaked at about 6,000 cfs during October 2003 storm. Flow at monitoring station LR1 is typically about twice that at the USGS station.

* Peak Storm Flow does not include the large storm in October, 2003 as this storm caused a much larger response than any previous storm during monitoring. This storm washed away many of the meters, so data for this storm are not available at all stations. See the comments for each station for any information about peak flow during this storm.

Overall, flows in the streams discharging to the Leon River are characterized by very low or no flow during dry periods with sharp spikes in flow during storm events. Spikes in response to rainfall typically last only one to two days at monitoring stations upstream of monitoring station LR1. Due to the much larger drainage area contributing to monitoring station LR1, elevated flow at this station due to storm events typically lasts much longer, generally exceeding one week. Flow at monitoring station SC5 is typically lower than at upstream stations under dry weather conditions. Monitoring station SC5 is frequently dry; however, flow spikes are higher here than at upstream stations during storm events. This observation based on estimated flows is corroborated by field observations. The highest dry weather flow upstream of monitoring station LR1 typically occurs at monitoring station SC3. Based on the groundwater and surface water level data presented in Section 5.1.3, the flow at station SC3 may be higher than the combined flow from upstream stations because stream reaches upstream of this monitoring station are typically gaining streams (See Chapter 6).

These observations are significant because they indicate that stream flow is lost to evapotranspiration or to groundwater between monitoring stations SC3 and SC5 under typical (non-storm) conditions. Therefore, very little, if any, surface drainage from the NWIRP area reaches the Leon River via surface flow during normal dry weather conditions. Dry weather flow reaching the Leon River from Station Creek is estimated to be typically less than 2% of the total flow in the Leon River at monitoring station LR1. During certain storm events recorded during this study, this percentage is conservatively estimated to be as high as 25%. Additional discussion on this flow as a component of inflow into Lake Belton is included in Chapter 6.

5.1.4.1.3.2 Bosque River Watershed

The portion of the Bosque River Watershed between NWIRP and Lake Waco studied during this investigation includes Harris Creek, the South Bosque River, and the Middle Bosque River downstream of the South Bosque River.

Bosque River Watershed Measured Data

Appendix O includes photographs of each stream monitoring location, plots of the surveyed cross-section, plots of the surveyed longitudinal centerline profile, and three-dimensional cross-section representations of the stream channel.

Two flow surveys were completed at six of the eight monitoring stations in the Bosque River watershed. Flows could not be measured at two of the monitoring stations: SBR5 and MBR1. As previously discussed, MBR1 was reported to be in the backwater of Lake Waco. Flow at SBR5 was likewise very slow. This station may also be affected by backwater from Lake Waco. **Table 5-11** summarizes the results of these flow surveys, including date and time, depth of stream at the bubbler location, and measured flow. As discussed previously in the methodology section, the second flow survey was completed following flooding that washed away all sampling equipment. Therefore, depths at the bubbler reported during the second flow survey may or may not comparable to depths reported during the first flow survey. The flow measurements are less sensitive to the exact measurement locations and therefore should be accurate for both surveys.

Table 5-11
NWIRP to Lake Waco Flow Survey Results

Station ID	**Flow Survey 1**			**Flow Survey 2**		
	Date/Time	Depth at Bubbler (ft)	Flow (cfs)	Date/Time	Depth at Bubbler (ft)	Flow (cfs)
HC1	3/4/03 12:40	0.85	47.13	10/16/03 12:35	0.75	12.20
HC2	3/4/03 14:50	1.50	55.18	10/16/03 8:30	1.05	13.31
SBR3	3/6/03 9:15	1.50	57.58	10/16/03 9:10	2.50	17.46
SBR1	3/4/03 17:00	0.80	56.36	10/16/03 13:05	1.70	7.62
SBR2	3/5/03 15:20	1.80	67.18	10/16/03 13:40	0.30	14.13
SBR4	3/5/03 17:45	1.90	79.82	10/16/03 14:10	1.50	10.53

Bosque River Watershed Flow Calculations

As discussed in the methodology section, flows were estimated over the duration of monitoring based on measured water level, channel geometry determined during surveying, and the Manning equation for uniform flow. Use of the Manning equation requires that certain channel properties be known or estimated. **Table 5-12** summarizes the slope and Manning's n values used at each station, including comments on how these values were estimated. Flows were not estimated at monitoring stations SBR5 or MBR1. Flows at these stations could not be measured during the flow surveys because flow was very slow and possibly affected by the backwater of Lake Waco. Use of Manning's equation at these stations would have led to highly erroneous results and there are no alternative data for comparison.

Table 5-12
NWIRP to Lake Waco Manning's n Values

Monitoring Station ID	**Manning's n**		**Comments**
	Main Channel	Flood Plain (winter/summer)	
HC1	0.11	0.16 / 0.20	Thick weeds on flood plain with some trees.
HC2	0.08	0.03	Relatively straight channel. Grassy floodplain.
SBR3	0.12	0.16 / 0.20	Thick weeds with trees on upper part of channel and on floodplain.
SBR1	0.11	0.04	Meandering channel with weeds. Grassy floodplain.
SBR2	0.10	0.16 / 0.20	Thick weeds with trees on floodplain.
SBR4	0.10	0.13 / 0.17	Trees and brush on floodplain.

Plots of the resulting calculated flows over the monitoring period duration are included in **Appendix P**. The two manual flow measurements taken at each site are also shown on these plots. **Figure 5-33** shows flows from monitoring station HC1 downstream to monitoring station SBR3 and **Figure 5-34** shows flows from monitoring station SBR1 downstream to monitoring station SBR4 for comparison between monitoring stations.

Verification of Calculated Flows.

Fewer opportunities for flow comparisons exist in the Bosque River Watershed than in the Leon River Watershed. However, calculated flows in the Bosque River Watershed could be compared against a few flow measurements and estimates from other sources to verify that flows were within a reasonable range. These other flow data included: manual flow measurements performed at each stream during this study; USGS data at nearby USGS monitoring stations; previous U.S. Navy flow data at sites upstream of station HC1; and visual observations by the project team in comparison to Leon River watershed stations.

Figure 5-33
Comparison of Flows at Monitoring Stations HC1, HC2, and SBR3

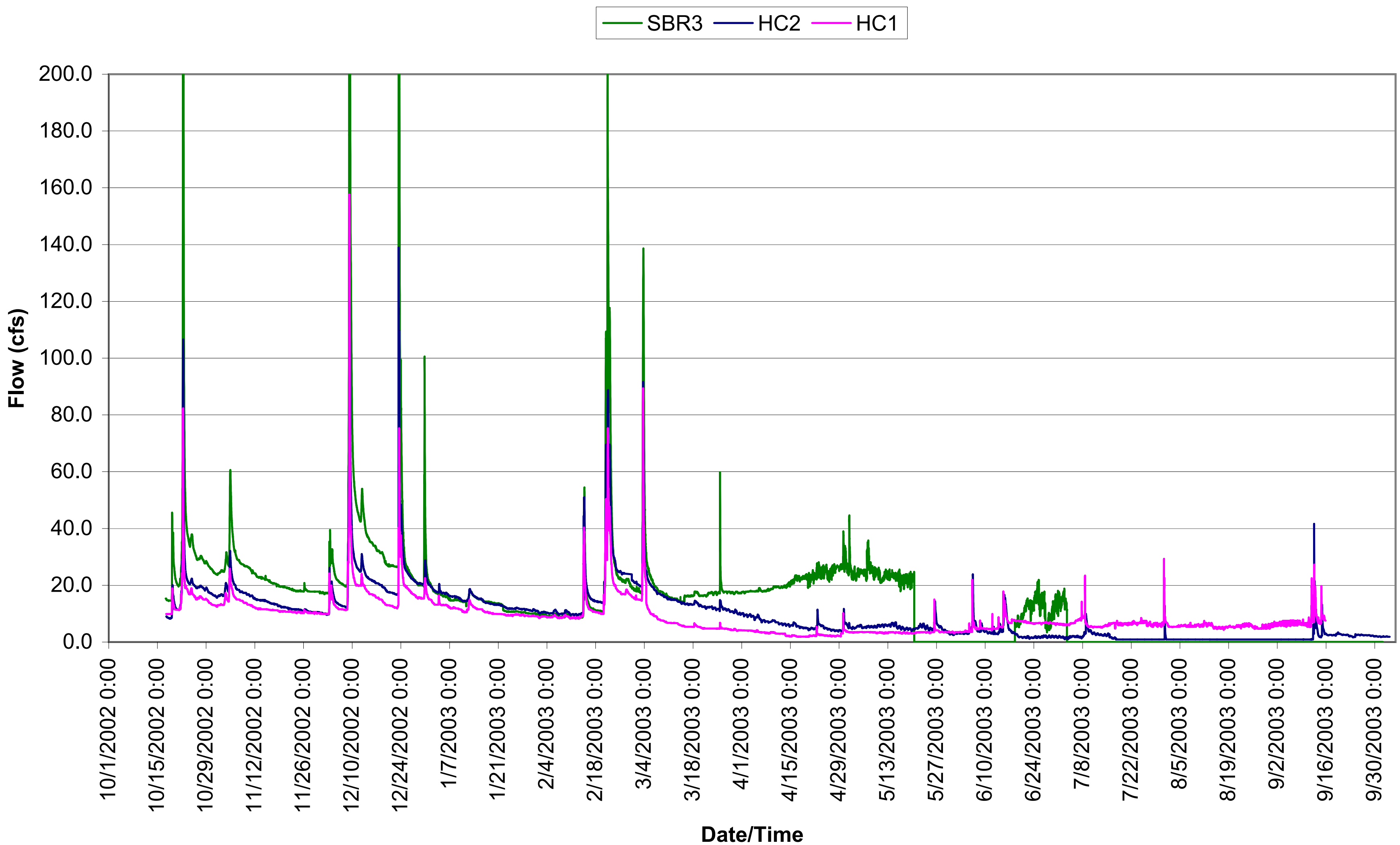
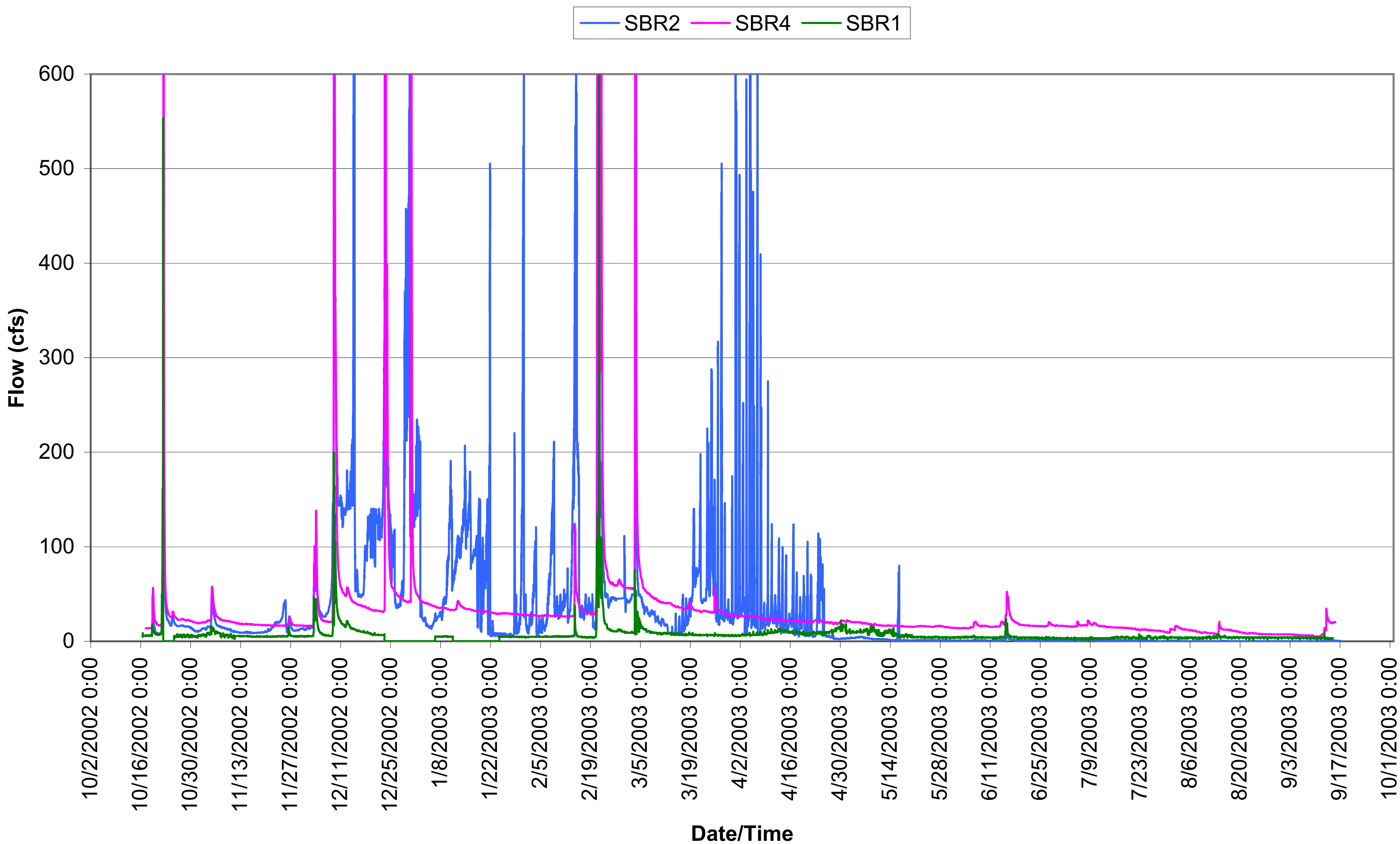


Figure 5-34
Comparison of Flows at Monitoring Stations SBR1, SBR2, and SBR4



Manual Flow Measurements. As discussed previously in this section, two manual flow surveys were completed during this study at each station not affected by backwater from the lakes. These manual flow measurements were plotted on the flow data graphs included in **Appendix P**. However, because the second flow survey was completed when several of the level meters were no longer in place, flow measured during this second survey could not be compared directly to a calculated flow at several stations. Additionally, at stations where level data were available during the second flow survey, flows calculated with Manning's flow equation could not match both the first and second flow survey measurements. Therefore, the stage-discharge curve for each station based on the calculated flows was plotted and compared to the flows and depths reported during the two flow surveys. As seen on these graphs, included in **Appendix P**, the calculated stage-discharge curve generally falls between the two manual flow survey points.

USGS Data. Two USGS stream monitoring stations exist upstream of monitoring stations for this study in the Bosque River Watershed. Unfortunately, flow data at these locations are not available during the period this study was conducted. However, these data could still be used to perform a limited amount of verification of calculated flows.

One of the USGS stations was located on the South Bosque River near McGregor, approximately 1.7 miles upstream of monitoring station SBR1. The only data available for this station were annual peak flows between 1967 and 1974. Reported peak flows ranged from approximately 200 cfs to approximately 4,200 cfs. Peak flow calculated at monitoring station SBR1 during this study was approximately 800 cfs, within the range of the USGS data.

The USGS also has a stream monitoring station on the Middle Bosque River approximately 8 miles upstream of station MBR1. Peak flows are available at this station from year 1959 through year 2001. Reported peaks at this station range from approximately 1,000 cfs to approximately 34,000 cfs, with most peaks around 10,000 cfs. While flow could not be calculated at station MBR1 or SBR5, this USGS station can at least provide some guidance in evaluating flows at SBR4 and SBR3. These two stations are located on the main tributaries discharging to SBR5, which is the largest tributary discharging to the Middle Bosque River downstream of the USGS station. Peak flows calculated at monitoring stations SBR3 and SBR4 are approximately 500 cfs and 3,300 cfs, respectively. These peak flows seem reasonable considering the peak flows reported at the USGS station on the Middle Bosque River.

U.S. Navy Data. The U.S. Navy collected data from several streams at or near the NWIRP site between March and May in year 2000. Two U.S. Navy monitoring stations are located approximately 3 miles upstream of monitoring station HC1 on tributaries to Harris Creek. The maximum peak in flow at these U.S. Navy stations that appeared to be due to rainfall totaled approximately 100 cfs. Therefore, the calculated peak flow of approximately 160 cfs at monitoring station HC1 seems reasonable.

Field Observations. The project field crew reported that flow in the streams monitored in the Bosque River Watershed typically (non-storm conditions) appeared to have more flow than observed in Station Creek and Tributary M in the Leon River Watershed. Additionally, unlike monitoring stations on Station Creek and Tributary M, stations in the Bosque River Watershed did not go dry at any time during this study. The observations support the flow calculations in that calculated dry weather flows in the Bosque River Watershed were significantly higher than in streams discharging to the Leon River.

Discussion of Bosque River Watershed Stations

The pattern of the calculated flow at each of these monitoring stations mimics that of the recorded water levels, with fairly low values during dry periods and rapid, sharp spikes following significant rainfall events. Since the pattern at each monitoring station was described in detail in Section 5.1.3, a detailed description of the response to rainfall events is not repeated here. **Table 5-13** summarizes the typical dry weather and storm flows estimated for each site.

Table 5-13
NWIRP to Lake Waco, Typical Flows

Monitoring Station ID	Typical Range in Dry Weather Flow (cfs)	Typical Range in Peak Storm Water Flow* (cfs)	Comments
HC1	2 – 15	60 – 160	Level data not available during October 2003 storm.
HC2	2 – 15	50 – 150	Peak flow of nearly 1,200 cfs during October 2003 storm.
SBR3	9 – 25	100 – 480	Level data not available during October 2003 storm.
SBR1	4 – 8	40 – 800	Level data during October 2003 storm not available.
SBR2	1 – 15	400 – 1,600	Dry weather flows highly variable due to apparent daily discharge from some source. Flows here are approximate natural flows. Flows due to apparent discharge reach much higher levels (hundreds of cfs). Likewise, it is difficult to discern the difference between peak flow due to rainfall and daily discharges. Level data during October 2003 storm not available.
SBR4	5 – 30	150 – 3,000	Level data during October 2003 storm not available.

* Peak Storm Flow does not include the large storm in October, 2003 as this storm caused a much larger response than any previous storm during the monitoring period. This storm washed away many of the meters, so data for this storm are not available at all stations. See the comments for each station for any information about peak flow during this storm.

As seen on **Figure 5-33**, flows at monitoring stations HC1 and HC2 were similar during non-storm conditions, with flow at the upstream station, HC1, slightly lower during the winter months. By June, however, flow at monitoring station HC1 was somewhat higher than flow calculated at monitoring station HC2, indicating that the stream reach between monitoring stations HC1 and HC2 lost water during the summer season to evapotranspiration or to groundwater. Flow farther downstream at station SBR3 was typically about the same or somewhat higher than at station HC2, but peak flows during storm events were typically two to three times greater at monitoring station SBR3 than those estimated at upstream stations.

As seen on **Figure 5-34**, average flow in the South Bosque River, characterized by monitoring stations SBR1, SBR2, and SBR4, typically increased from upstream to downstream. As in Harris Creek, however, this trend appears to change during the summer months, with calculated flow at upstream monitoring station SBR1 exceeding flow at monitoring station SBR2. Again, this change indicates that this stream reach loses more water to evapotranspiration or to groundwater than it gains from tributaries during the summer.

Monitoring stations along the South Bosque River also showed some daily fluctuations in flow not observed at other stations. Fluctuations at monitoring station SBR1 are small, approximately one to two cfs, with a daily peak in flow around 4:00 PM. This magnitude of flow change is on the order of what might be released from a small sanitary WWTP and could be due to discharges from an upstream plant. Monitoring station SBR2, approximately 5 miles downstream from SBR1, showed very large daily fluctuations in flow, on the order of hundreds of cfs, during part of the monitoring period. The validity or potential cause of these fluctuations is unknown. These fluctuations are not apparent downstream at monitoring station SBR4.

Although flows are unknown at monitoring stations SBR5 and MBR1, a general estimate of the amount of flow reaching these stations from Harris Creek and the South Bosque River can still be made. Flow at monitoring station SBR5 is expected to come primarily from these upstream monitoring stations on the South Bosque River and Harris Creek, as tributaries flowing into the South Bosque River between SBR4 and SBR5 appear to be very small. The amount of flow reaching the lower South Bosque River (SBR5) from the Harris Creek route (HC1, HC2, SBR3) is likely similar to that from the South Bosque route (SBR1, SBR2, SBR4) during dry weather. However, peak storm flows coming from the South Bosque River could be up to four times greater than those from Harris Creek. Sufficient data are not available to estimate the percentage contribution of flow from the South Bosque River to the Middle Bosque River, although it is thought to be somewhat higher than the contribution of Station Creek to the Leon River as discussed in the previous section. Further information on estimated flows compared to the total flow entering Lake Waco is included in Chapter 6.

5.1.4.1.3.3 Cowhouse Creek

As discussed previously, flows were not calculated at Cowhouse Creek because this monitoring station was reported to be in the backwater of Lake Belton. However, a photograph of the stream at station CHC1, a plot of the cross-section, a plot of the centerline profile, and a three-dimensional representation of the cross-section are included in **Appendix O**.

5.1.4.2 Lakes (ADCP)

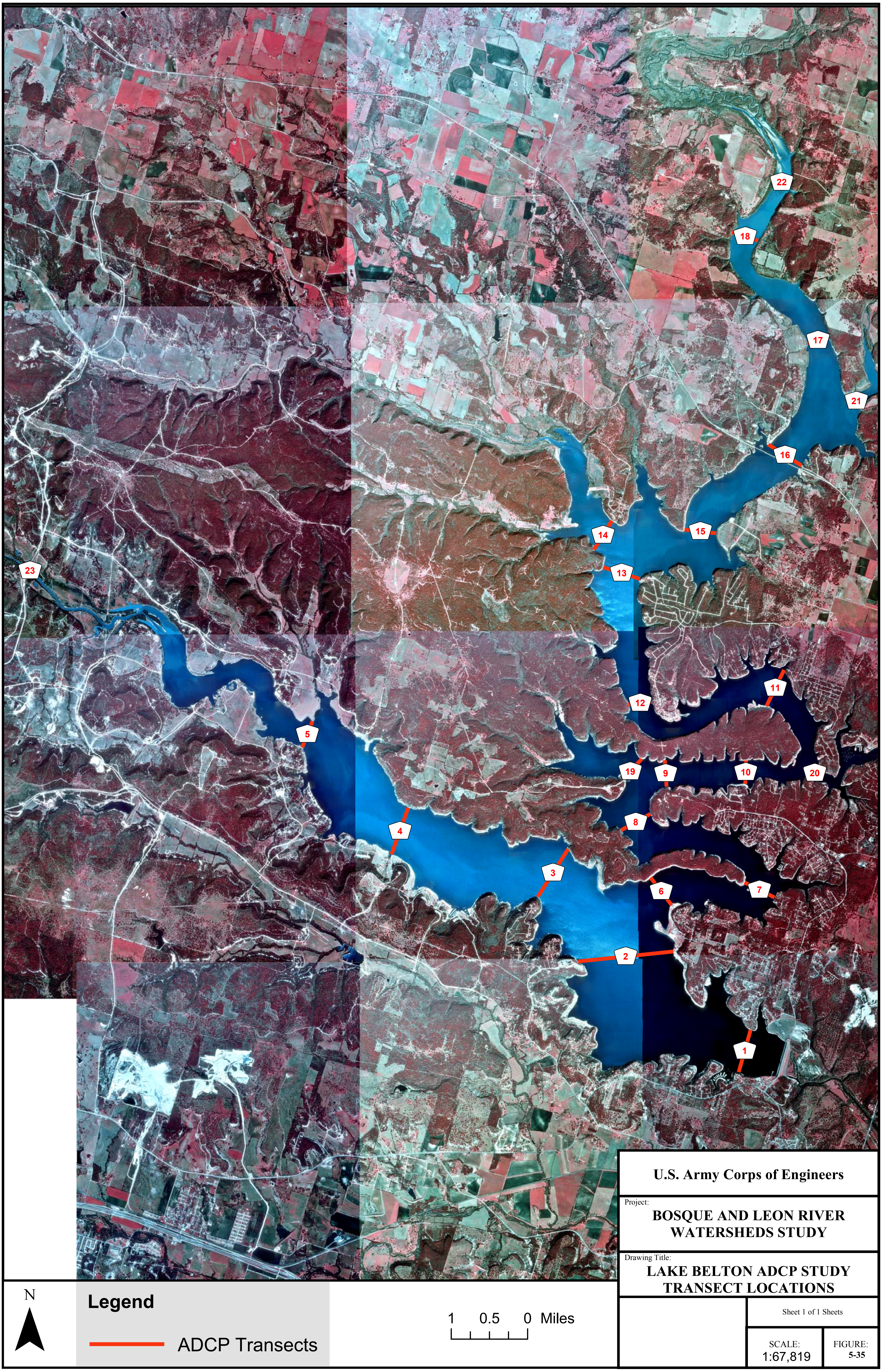
The Acoustic Doppler Current Profiler (ADCP) was first shown to be a promising tool for determining river current velocity in 1982 (USGS, 2001). ADCP equipment is now used to measure current velocity in oceans, lakes, rivers, and estuaries. ADCP is used over a wide range of depths and varying field conditions making it a powerful tool for the measurement of water current velocity in settings where conventional discharge measurements could not previously be performed.

The ADCP equipment measures water velocity using a principle of physics known as the doppler shift, where the change in frequency of a source of sound is related to both the velocity of the source and the observer. ADCP functions by emitting sound waves from near the water surface to the bottom of the water body. The ADCP equipment bounces an ultrasonic sound pulse off small particles of sediment and other material being carried by the current in the water column (collectively referred to as backscatters) and records the return echo from the acoustic backscatters. Upon receiving the return echo, the ADCP's onboard signal processing unit calculates the Doppler shift and thus determines the velocity of the backscatters, which is equal to the velocity of the water.

For this study, an ADCP was attached to a boat and used to determine current velocity at 21 transects, as shown on **Figure 5-35**, by motoring across Lake Belton. A total of four ADCP measurements were obtained at all transects, one during each season of the year, in order to better understand how lake currents change throughout the year and to ascertain what effect changing flow patterns may have on perchlorate fate and transport.

The overall rationale for the selected ADCP transects was to survey specific locations within the lake that could be helpful in identifying flow patterns within the lake, especially potential deep-water currents that were hypothesized to exist along the old river channel or thalweg of the lake. These deep-water currents, if encountered, could provide a preferential flow path for perchlorate that may be entering the lake.

The transect locations were selected based on a review of historical topographic maps, to provide an evenly spaced distribution along the length of the thalweg. Transects were also located at the mouths of major streams entering the lake. Three transects were located near the Bell County WCID No. 1, Blue Bonnet, and City of Gatesville water intake structures to determine if any preferential flows within the lake are located near these structures. The ADCP survey was limited to Lake Belton based on the assumption that Lake Waco is a more well-mixed, homogeneous environment, both because of its shallow configuration and the presence of a mechanical aeration system.



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In addition to the 21 original transects, an additional transect across the Leon River was conducted during the summer, fall, and winter surveys to assist in estimating flows in this stream and to validate calculated sampling station flow meter readings. Also, an additional transect across Cowhouse Creek was conducted during the fall survey to obtain better information about the discharge flows into the lake from this creek. This portion of the Study was conducted as part of the Acoustic Doppler Current Profiler Survey. All the methodologies and protocols followed during these studies are detailed in the *Final Lake Belton Acoustic Doppler Current Profiler Field Sampling Plan* (MWH, 2003). Any deviations from the Field Sampling Plan are discussed further below.

5.1.4.2.1 Methodology

Pre-Survey ADCP Activities. Prior to deployment of the ADCP, the instrument's compass was calibrated on land according to manufacturer's guidelines. Following compass calibration, the ADCP was attached to the side of the boat using a special mount and set at a depth of at least three inches below the water surface based on the manufacturer's guidelines. The depth to which the ADCP was installed below the water surface was recorded in the field notes. The ADCP was programmed, operated, and maintained according to the manufacturer's guidelines by an experienced professional.

ADCP Survey Activities. An ADCP pre-run was performed at the beginning of each field day to verify that all equipment was functioning properly. An experienced boat operator controlled the boat across the transect in order to ensure representative and accurate ADCP data. Each transect was completed in order to obtain depth and current profiling data, and each transect was completed by guiding the boat along the pre-determined transects across the lake toward the end point at a rate no greater than 6 knots. Data acquisition began by estimating the distance from shore and recording the transect starting point location using GPS. The distance from shore and GPS location were determined at the transect endpoint. The locations of some of the transects were changed based on field conditions, observations, or lack of accessibility by boat, and the geographic positioning system (GPS) coordinates for both the starting and end points of each transect were recorded. Following data acquisition, the ADCP was turned off, pulled out of the water, and data were checked for quality and accuracy prior to moving to the next transect. A temperature profile of the lake was then obtained at the deepest point of each transect, and temperature measurements were recorded at ten-foot intervals from the surface to the bottom of the lake. ADCP survey activities were halted if the boat and ADCP equipment operators determined that wave and wind action was unsafe or would prevent the collection of representative and accurate data.

A boat was used to complete the ADCP transects across Lake Belton, as shown above on **Figure 5-35**. The following equipment was utilized to perform the ADCP survey:

- 600 kHz Rio Grande or Sentinel ADCP Workhorse with bottom-tracking capability
- Differential GPS (to be used if bottom-tracking is hindered due to high sediment conditions)
- Power supply and communications interface

- Velocity profiling and measurement software
- Manufacturer's documentation

Additional Equipment. The following ancillary equipment were utilized during the ADCP survey:

- Boat (non-steel hull)
- Mounting assembly for connecting ADCP and GPS equipment to the boat
- Laptop computer
- Handheld GPS
- Seabird SB19 CTD Profiler (temperature)

ADCP data were collected in blocks or ensembles across the entire cross-section as the boat traveled across each transect's length from the lake surface to the lake bottom. After the ADCP instrument completed a single data collection, it sent a block of data called a data ensemble to the laptop. A data ensemble consists of the data collected and averaged during the ensemble interval. A data ensemble can contain header, leader, velocity, correlation magnitude, echo intensity, percent accuracy, status, and bottom-track data. The slower the boat traveled the more ensembles the ADCP was able to generate for each transect's cross-section. The ADCP collects current speed and direction at multiple depths through the water column, excluding the upper and lower one-meter. Profiles of current data with navigation fixes were collected every three seconds at vessel speeds of approximately 2.5 knots, and were logged directly to a laptop computer. Discharge measurements were calculated by the ADCP software, making assumptions for the near bank volumes and the areas of no measurement near the surface and near bottom. The boat speed, during the field surveys, was kept to a minimum but speeds were varied slightly, depending on wind speed to keep the boat on course, and to prevent drifting away from the pre-determined transect location. Ensemble size changes can be seen in **Appendix Q**, which show differing sizes of data ensembles for the same transect for the spring, summer, fall, and winter surveys. The ADCP data generated (the combined ensembles) produced current velocity profiles across each transect.

5.1.4.2.2 Data

Current and temperature profiling of Lake Belton were carried out on March 17, 2003 (Spring), June 16 and 17, 2003 (Summer), September 22 and 23, 2003 (Fall), and December 10, 11, 15, 17 and 18, 2003 (Winter).

Navigation software provided spatial positioning for the vessel operator during the transect crossings using real time navigation software receiving Wide Area Augmentation Satellite Differential GPS fixes. Current data with navigation fixes were logged directly to a laptop computer. Current values were collected at 0.5-m vertical intervals.

Profiles of current data with 0.5-m vertical resolution were recorded every 3 seconds at vessel speeds of approximately 2.5 knots, which generated velocity contour plots included in **Appendix Q**. Discharge measurements or core flows were calculated by the

ADCP software, making assumptions for the near bank volumes and the areas of no measurement near the surface and near bottom.

Temperature profiles were developed at the deepest part of each transect by collecting temperature data using a Seabird SB19 CTD profiler. This instrument records temperature data at a frequency of 2 hertz. Temperature profiles were collected by lowering the SB19 to the lakebed and retrieving it to the surface while it logged temperature data internally. Recorded profiles were downloaded to a laptop computer and converted to degrees Celsius. Temperature profiles for the different transect locations in Lake Belton are included in **Appendix R**.

Using the velocity contour plots generated by the ADCP, core flows were generated across each transect. These core flows are depicted in **Plate 2** through **Plate 5**. The length of the arrow indicates the magnitude of the flow, while the arrowhead itself indicates the direction of flow.

Data Limitations

Currents. Current data collected with acoustic tools are derived from measurements of particulate velocities in the water column. The final reported current velocity is a statistical product of numerous samples of water particulate velocity. As a result, the error of a current measurement decreases as the sample volume and number of samples averaged together increases.

The cost of averaging is a loss of resolution both vertically in the water column and horizontally across the transect. The goal of locating core flows in thalwegs of several meters width dictates a maximum number of consecutive profiles that may be averaged together before the core flow data become "smeared" into the adjacent flow values. To achieve the highest level of horizontal resolution, the number of profiles can be increased (by traveling very slowly across the transect) and the vertical resolution can be decreased (by extending the sample bin size).

Vessel speeds during the survey were kept to the minimum possible to maintain steerage across the transect. Vertical sample bins were set to 0.5 meters. Having observed little vertical flow structure in the transect flows of the initial survey, the vertical bin size could be increased during subsequent surveys but with the risk of missing the thalweg by over-averaging the bathymetry near bottom. The thalweg of transect 16 (spring) was observed with 0.5-meter vertical resolution as approximately 1 meter deep below the streambed. If the vertical resolution were decreased to 1 meter, the thalweg would not appear as an obvious feature, frustrating the goal of locating thalweg flow patterns.

The operator recognizes inaccurate data as blank profiles or individual profiles of anomalous high or low value. The key to observing a realistic current feature is to collect multiple profiles with a meaningful trend in a contiguous section of the channel. Wide variations in current direction in low flow conditions should not be considered an indicator of bad data. As velocities approach zero, direction becomes expectedly less meaningful.

Discharge. The ADCP incrementally calculates discharge by summing volumes of flow as the vessel crosses the channel. While the summation process averages the entire velocity field of a transect, reducing the effects of single profile variability, other sources of error affect discharge calculations when flow assumptions are not met.

In areas of very low flow, discharge values are subject to errors due to variations in the circulation on a transect of the same temporal scale as the length of time to make the transect. In some cases, circulation variations, such as eddies, can form and dissipate, or translate across a channel during the time it takes a vessel to cross. This condition can cause large errors in the discharge measurements reported by the ADCP because the condition of steady flow for the period of the transect measurement is not met. Several discharge measurements in the southern area of the survey between adjacent transects corroborate well, with a few obvious bad values. Discharge values in the shallow, low-flow transects of the north transects are less reliable. Discharge values that are not supported by adjacent values are labeled “not supported” on the contour plots.

Temperature. The temperature system of the Seabird SBE19 profiler is extremely robust and has very few sources of data error aside from obvious sensor failure.

5.1.4.2.3 Discussion

The discussion of the ADCP-Lake Flow section is divided into five separate sub-sections to provide information and explanation of the data collected, allow individual discussion of the current velocity profiles, and discuss the temperature profiles collected during each of the four seasonal surveys that were conducted. The five discussion topics are as follows:

- Spring Data (spring survey)
- Summer Data (summer survey)
- Fall Data (fall survey)
- Winter Data (winter survey), and
- Discussion Summary

5.1.4.2.3.1 Spring Data

Currents

Extremely small currents hampered the understanding of the circulation of Lake Belton during the spring survey. Maximum flow cores were measured near 0.3 m/s. While stationary bottom mount ADCPs looking up from the lake bed can resolve extremely small currents, vessel mount surveys are limited by the need to progress across a transect at a reasonable speed. Transect 18 was too shallow to provide current data. It did provide a very short CTD profile.

Several transects provide evidence of slightly increased flow in the submerged thalweg **(Figure 5-36)**. Many transects show uniform magnitude fields of non-directional flow **(Figure 5-37)**. In these areas, flow may be dominated by non-riverine influences such as density variations, and surface winds. At least one transect showed a distinct flow core in mid-channel, outside the thalweg **(Figure 5-38)**.

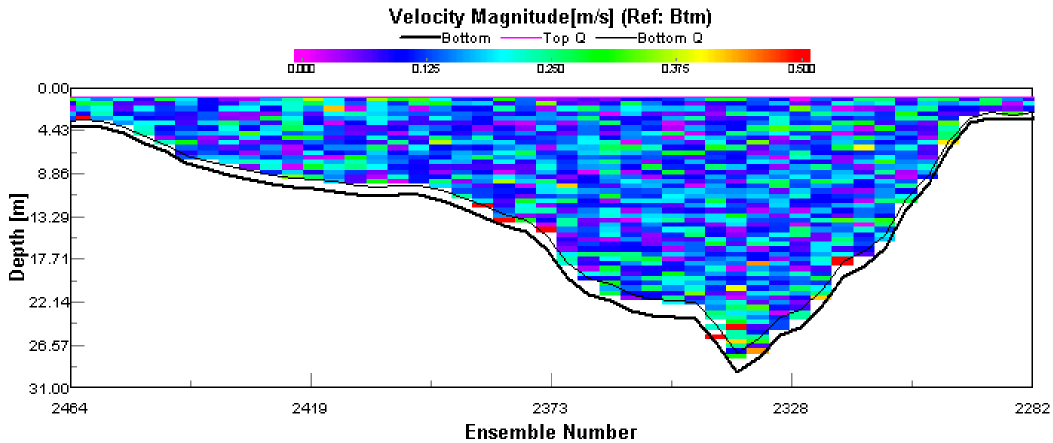

Figure 5-36
Increased Flow in the Bottom of a Thalweg, Transect 6

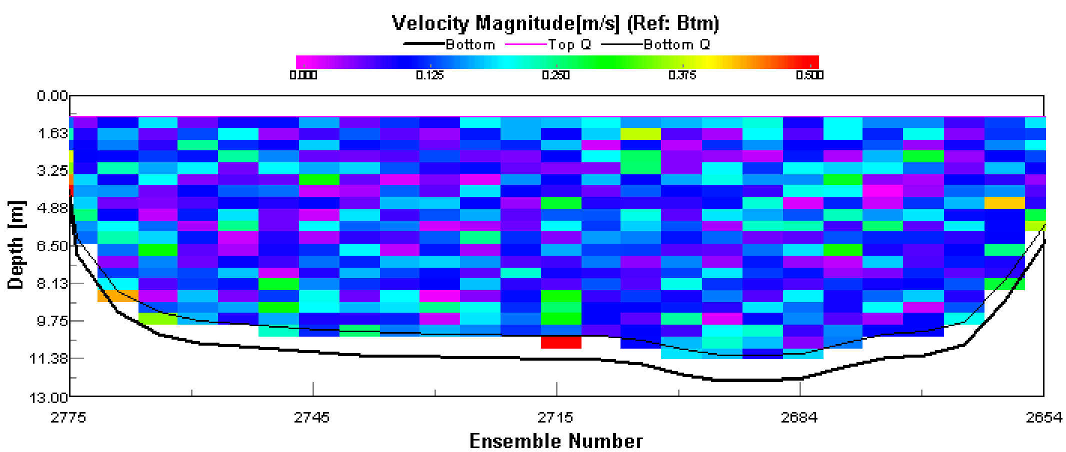

Figure 5-37
Uniform Flow, Transect 12

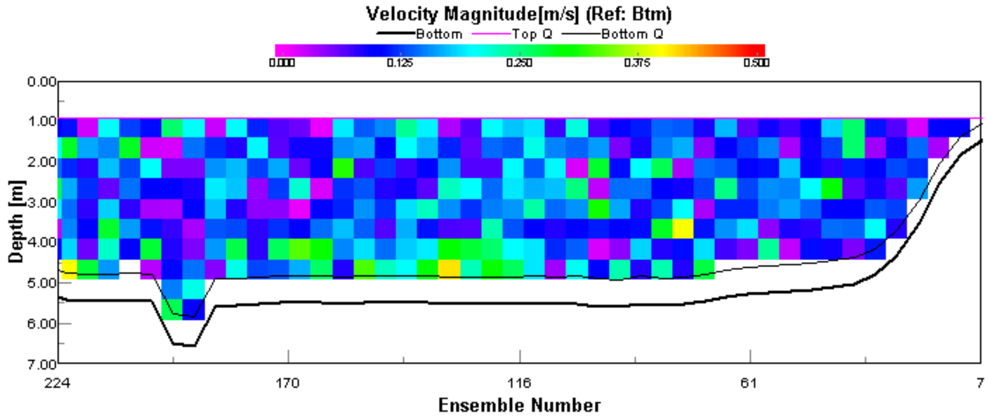

Figure 5-38
Channel Center Flow Adjacent to Thalweg, Transect 16

The following regional trends of core flow location were observed:

- Southern portions of Lake Belton (transects 1, 2) and the Cowhouse Creek branch (transects 3, 4, 5) are most likely to have thalweg flow.
- Central channel flow in the central section of Lake Belton (transects 6 to 13) may have slight thalweg flow.
- Lake channels north of transect 13 show very slight flows unconfined to the thalweg and often nondirectional. Where flow cores are observed they may be channel centered or adjacent to a bank.

Discharge
While it would be unwise to use collected discharge values for volumetric calculations, it is possible to observe the following area trends:

- The Cowhouse Creek branch (transects 3, 4, 5) provides nearly half the flow into the southern portion of Lake Belton (south of transects 3 and 6) with values near 60 m^3/s.
- The central channel of Lake Belton at transect 6 provides a similar flow into the southern portion of Lake Belton south of transects 3 and 6.

Temperature
Temperature profiles in the lake channels typically show a well-mixed surface layer with a distinct thermocline at 2 – 5m deep (Figure 5). By 12m depth, temperature becomes isothermal, near 10 °C.

5.1.4.2.3.2 Summer Data

Currents
Current data for the June survey cruise showed two primary flow regimes. In the southern lake transects, wind dominant currents appeared in the upper levels of the lake. These wind driven currents tended toward the up-channel direction, often confined within the

thermocline layer and against the core flows. Few concentrated core flows were observed in the south.

In the northern channels where river flows were observed, two-layer flows dominate with surface waters moving down-channel and deeper currents flowing up-channel.

Few areas of core flow were confined in the channel thalweg. Obvious instances of thalweg flow were up-channel as part of a circulation cell.

Measured discharge values are not likely to be accurate due to several factors including:

- Variations in wind driven circulation on the same time scale as the period of the transect
- Extremely low flow conditions
- Eddy conditions with shifting centers of circulation on the same time scale as the period of the transect

Temperature data show strong thermoclines in areas of vertical multi-layer flow in the southern channels. Northern channels that exhibit horizontal flow layers show constant temperatures with depth in the channel thalwegs.

Wind Effects
Maximum current velocities in the southern transects were found in the surface wind dominated layers **(Figure 5-39)**. These currents are frequently opposite in direction to the channel flow.

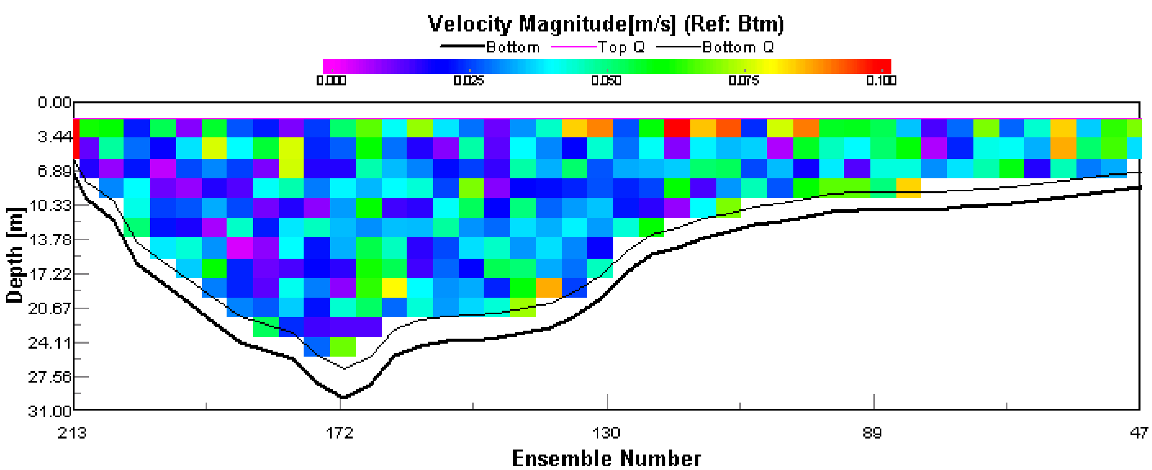

Figure 5-39
High Velocity Wind Drive Currents Above 5-m Depth, Transect 6

Wind speeds and direction varied during the survey. Gusty conditions of approximately 15 knots endured for short periods. Wind directions varied with location possibly due to the effects of the high channel banks on the prevailing southwest breeze.

Eddy Conditions
Reverse channel flows were observed in a number of transects. These features may be combinations of the wind effect, basin geometry, and core flow. In southern lake channels, wind driven currents appear near the surface with higher magnitudes while slow lake water below the thermocline flowed in the opposite direction.

Closer to the Leon River, reverse channel flows were observed along several transects. These reverse flows were deeper and on one side of the channel while an opposing river flow appears shallower on the opposite side **(Figure 5-40, Figure 5-41)**.

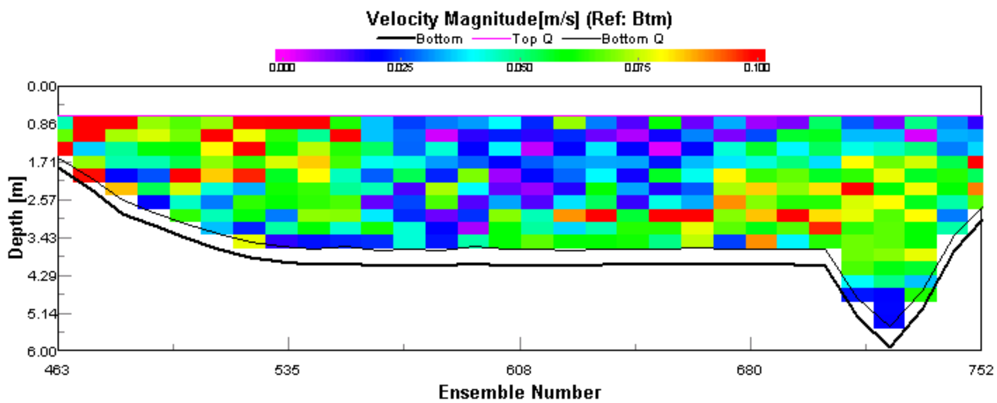

Figure 5-40
Eddy Flow, Two Core Magnitudes, Transect 17

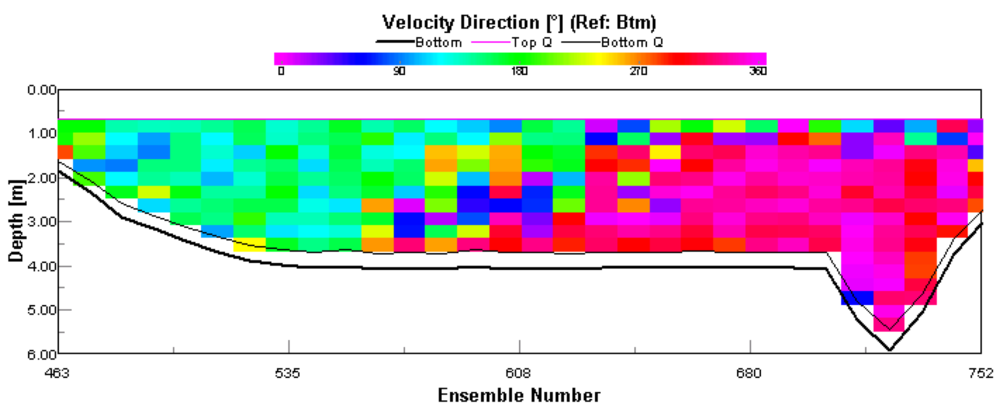

Figure 5-41
Eddy Flow, Southward (Green) Northward (Red), Transect 17

Discharge
Of all the collected transects, only the final measurement in the Leon River should be considered as an accurate measure of discharge. This transect showed strong laminar stream flow without effects of wind or eddies **(Figure 5-42)**.

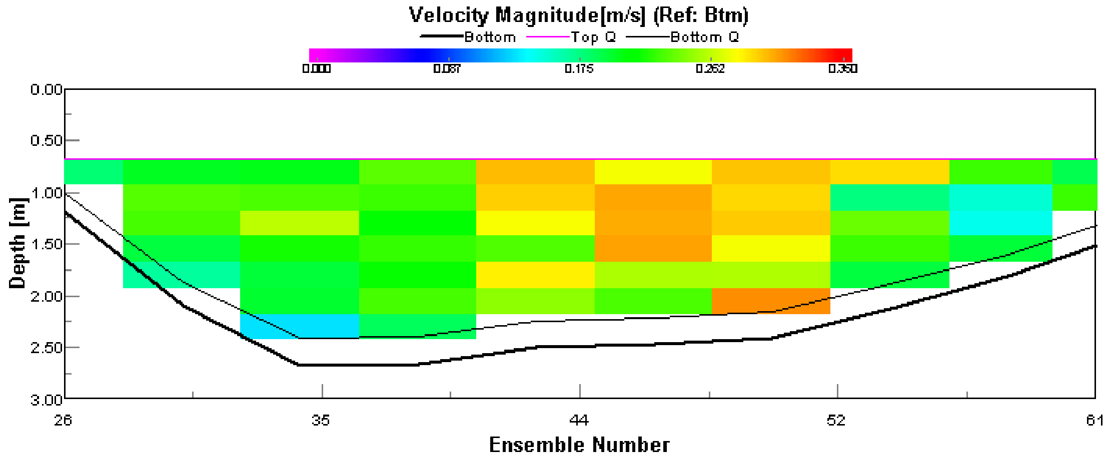

Figure 5-42
Laminar Stream Flow Discharge of 16.3 m^3/s, Transect 22 Leon River Section

Eddy circulation has a negative effect on discharge measurements. The value recorded for transect 17 **(Figure 5-40, Figure 5-41)** was 1.8 m^3/s. An accurate discharge measurement upstream from transect 22 in the Leon River showed 16.3 m^3/s. It seems clear that the Leon River flow should be conserved downstream at transect 17, suggesting that eddies can affect discharge measurements in the area by close to a factor of 10.

Thalweg Flow

Bottom flow was only apparent in a few transects **(Figure 5-43)**. Transects 15, 16, and 17 showed the bottom flow conditions characteristic of northern lake sections as the deeper half of a two-layer flow **(Figure 5-44)**. In these cases, flow was observed within the thalweg but flowing up-channel. Surface currents in the northern lake sections may represent core flows. The Leon River temperature sample showed the river to be one degree warmer than lake surface water suggesting that river water may override the lake water while the temperature difference endures.

These conditions are a departure from the observations of the spring survey. In March 2003, different wind directions, lake stages, and temperature structures in the river and lake created conditions of intuitive channel flow where maximum current magnitudes were more likely to be observed in the thalwegs as high velocity cores flowing down channel. The June 2003 conditions are characterized by wind effects, eddies, and uniform-slow channel flows below the thermocline.

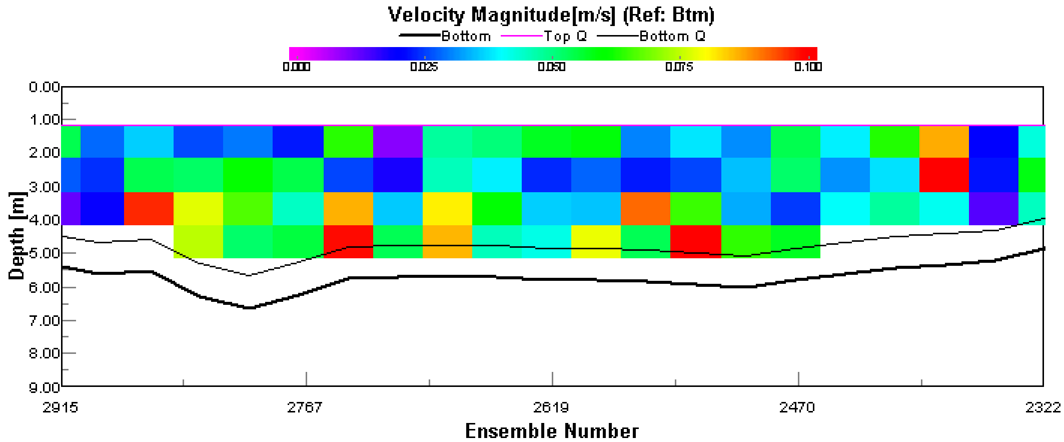

Figure 5-43
Bottom Flow Magnitude, Transect 16

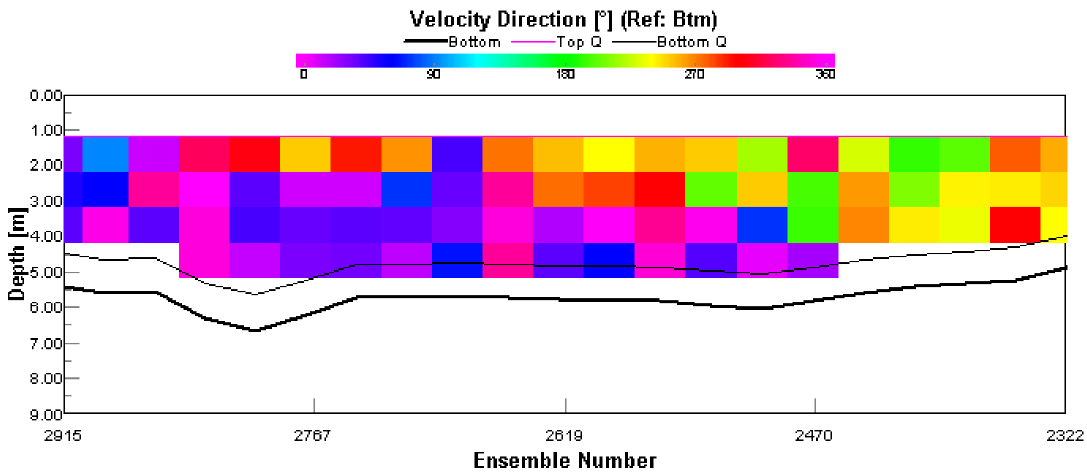

Figure 5-44
Bottom Flow Direction Up Channel (Purple/Blue) and Down Channel (Green/Yellow), Transect 16

Temperature

Lake and river temperatures were nearly 22 °C warmer in the summer (June 2003) than during the spring survey. Temperature ranges were much reduced in June, spanning only one degree. Surface water ranges in the spring (March 2003) were near 4 °C. Strong thermoclines were observed at all southern channel transects, which occurred near 8-m depths. Measurements north of transect 15 are well mixed with no thermoclines evident. Current data suggest that a temperature profile taken in the thalweg would be uniform. In these northern transects, temperature stratification in the channel may be horizontal across the channel and not vertical with depth.

<u>*5.1.4.2.3.3 Fall Data*</u>

Currents

Currents measured during the fall (September) survey were extremely low. The lake water level was the lowest observed during the study. Areas of measurable flow in June, such as the Leon River transect 22, were impassable in September. Transect 18 was too shallow to collect usable data. Measurements at transect 21 appear to be unrealistically out of range. A computer crash required the software to be reloaded just prior to this transect.

Similar complex trends of wind driven surface flow, channel eddies, and reverse currents were observed but appeared less vigorous than in earlier surveys. Few instances of significant core flow were observed. Several of these slightly higher flows were observed near the thalwegs, often above the submerged banks but centered on the thalweg **(Figure 5-45)**.

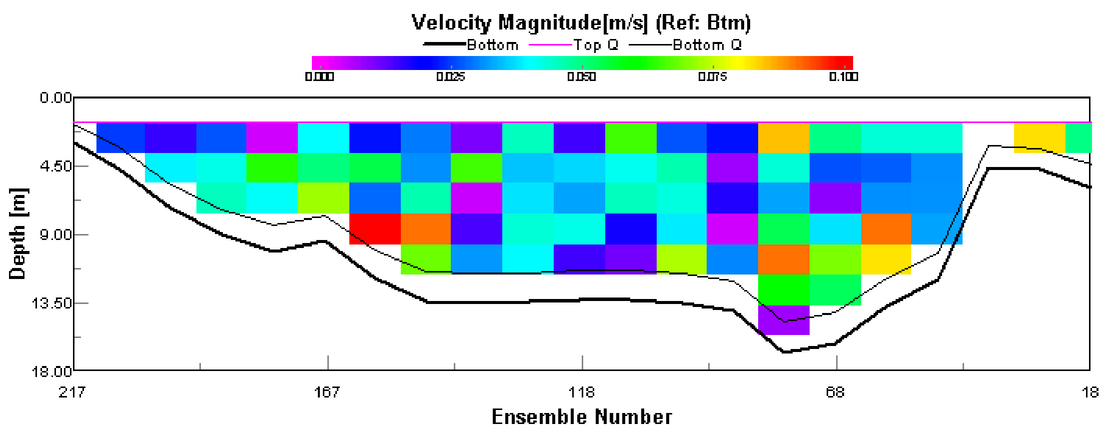

Figure 5-45
Core Flow Near a Thalweg, Transect 11

Measured discharge values are not likely to be accurate due to several factors including:

- Variations in wind driven circulation on the same time scale as the period of the transect.
- Extremely low flow conditions.
- Eddy conditions with shifting centers of circulation on the same time scale as the period of the transect.

Temperature data show strong thermoclines in areas of vertical multi-layer flow in the southern channels.

Wind Effects

Wind speeds were generally light during the survey period. Some instances of wind effect correlate to periods of building breeze during the transect **(Figure 5-46)**. Wind directions varied with location possibly due to the effects of the high channel banks on the breeze. These effects seem to cause shore-parallel wind directions regardless of the wind direction at elevations above the channel banks.

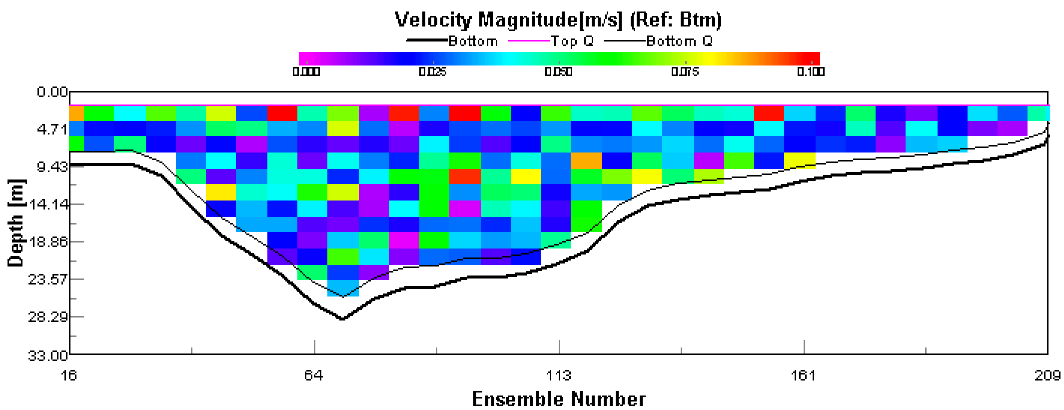

Figure 5-46
Surface Wind Current Effects During Breeze, Transect 6

Eddy Conditions

Good examples of diagonal shear layers across the channel were collected in spite of extremely low flow conditions. Reverse channel flows were observed in a number of transects **(Figure 5-47**, **Figure 5-48)**.

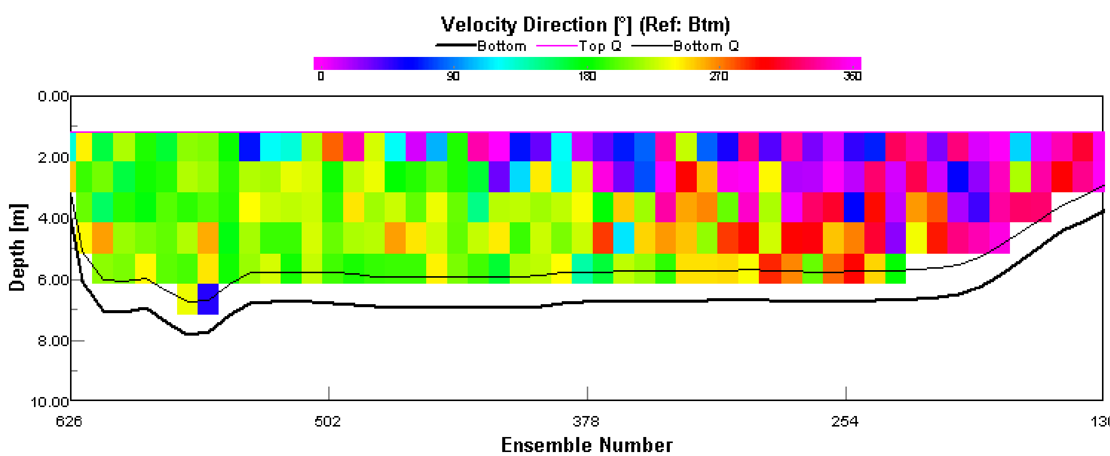

Figure 5-47
Diagonal Shear with Reverse Flow on Upper Right and Lower Left, Transect 15

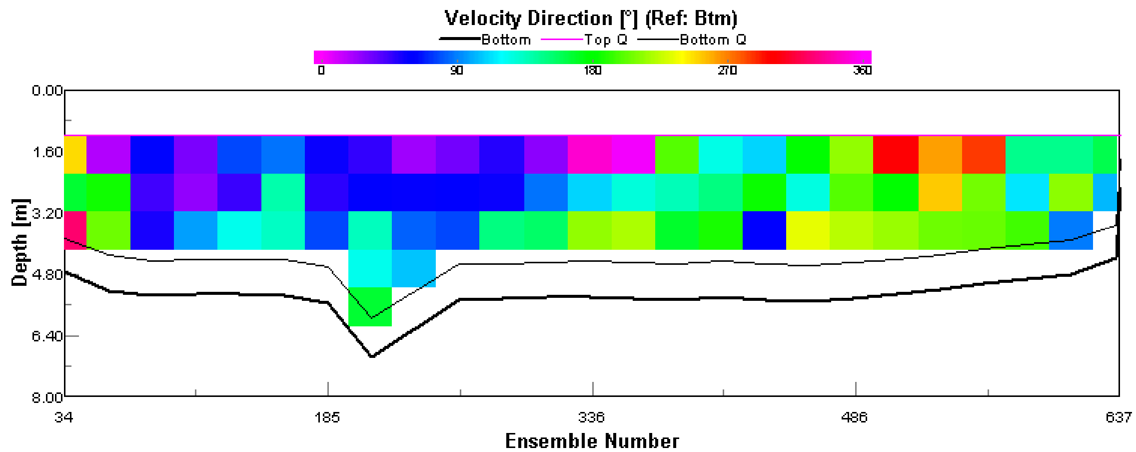

Figure 5-48
Diagonal Shear with Reverse Flow on Upper Right and Lower Left, Transect 16

Other examples show eddy circulation at a single depth **(Figure 5-49)**.

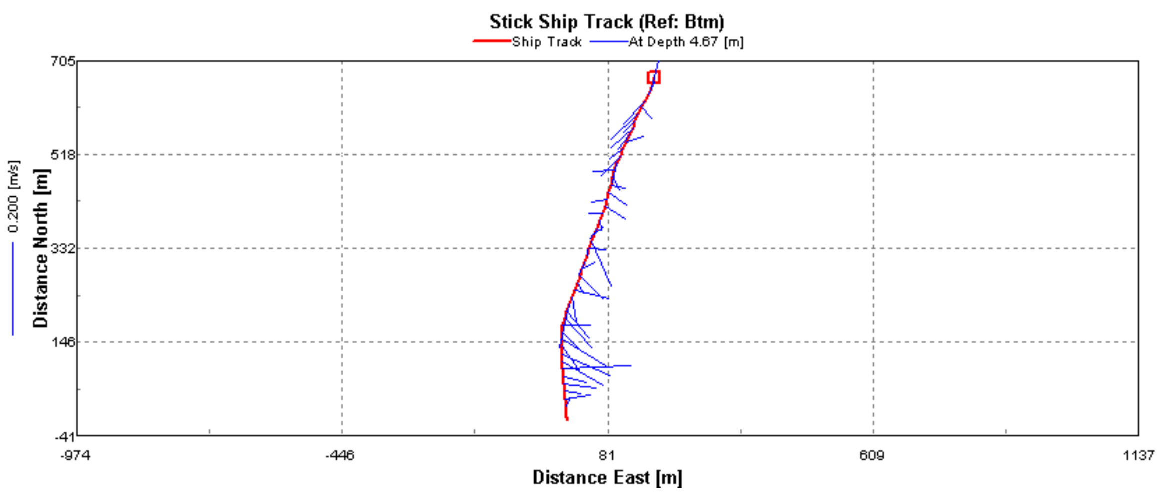

Figure 5-49
Vector Flow Diagram of Eddy Flow at 4.67m Depth, Transect 14

Discharge

Discharge measurements were frustrated by the extreme low flows. Multiple measurements were made at transect 23 with some success. Currents were too slow to observe “by eye” during collection of these transect data, but were recorded as laminar channel flow by the Rio Grande ADCP **(Figure 5-50)**.

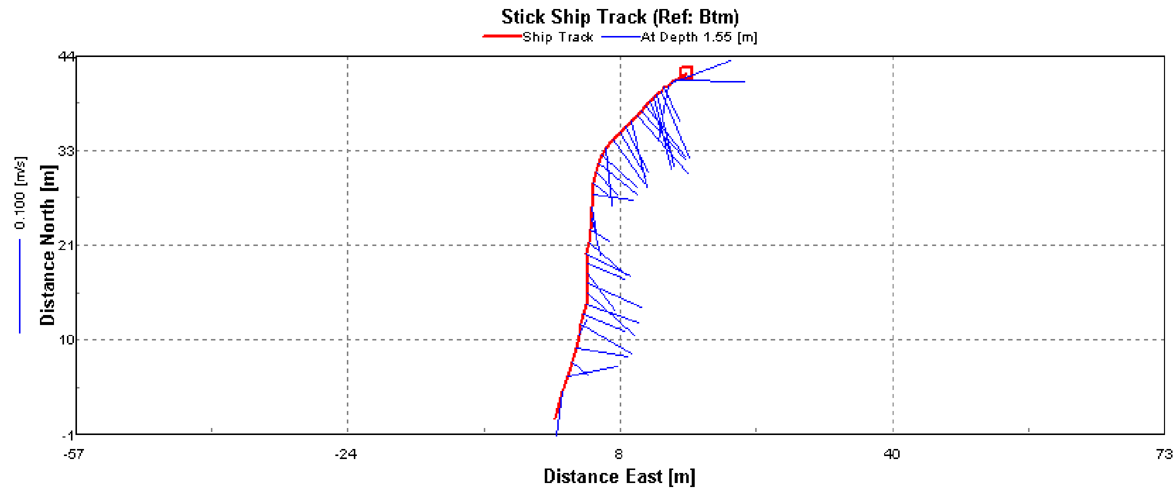

Figure 5-50
Vector Flow Diagram of Laminar Channel Flow at 1.55m Depth, Transect 23

Discharge values measured in the lake channels follow some plausible trends with a number of obviously bad discharge values. These include unlikely values at transects 1, 2, 10 and 11. Use of these data for summation of discharge rates for any purpose other than very general trend observations is not advisable. One additional source of discharge to be considered is the possible existence of submerged springs and seeps.

Thalweg Flow
Thalweg flows, although not obviously apparent and at very low velocities, are detected in a few transects. As with the previous survey, flow near the thalweg is often the deeper half of a two-layer flow **(Figure 5-51, Figure 5-52)**.

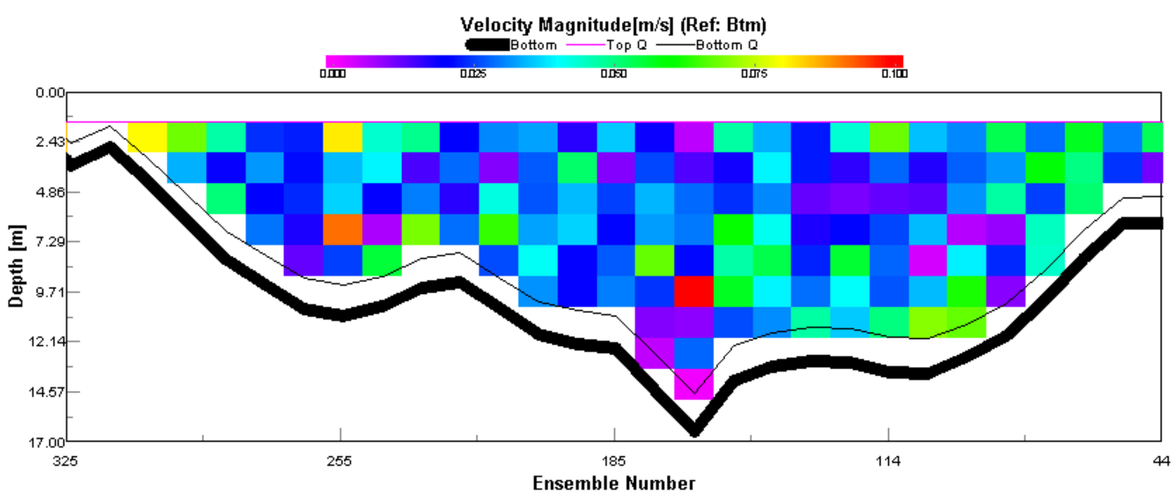

Figure 5-51
Thalweg Flow Velocity, Transect 4

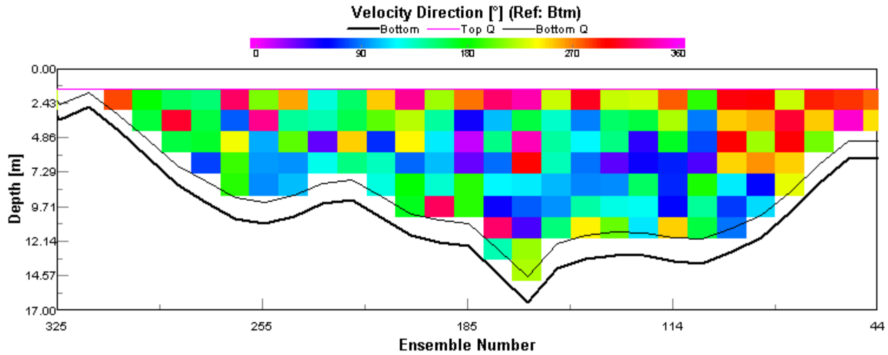

Figure 5-52
Opposite Surface Flow Direction Above Thalweg, Transect 4

Temperature
Southern lake channel surface temperatures are nearly identical to the June survey. Lake surface water temperature ranges are more consistent with this survey, spanning only 1 °C, and remain warmer to a deeper more abrupt thermocline at 11m. Measurements north of transect 15 are again consistent to depth and present no evidence of thermocline.

5.1.4.2.3.4 Winter Data

Currents
Currents measured during the December 2003 survey were again extremely low and chaotic. ADCP transects collected on December 17th, during calm weather, produced excellent data. All other transects were performed in windy conditions with wave chop affecting the upper water column data. Through averaging of ensembles and observance of data in Velocity Direction as well as Velocity Magnitude contour plots, core flow data were extracted from each transect. As in **Figure 5-53** where surface data are "noisy" and lack directional continuity, yet the data near the lake bottom produced ensembles of common direction.

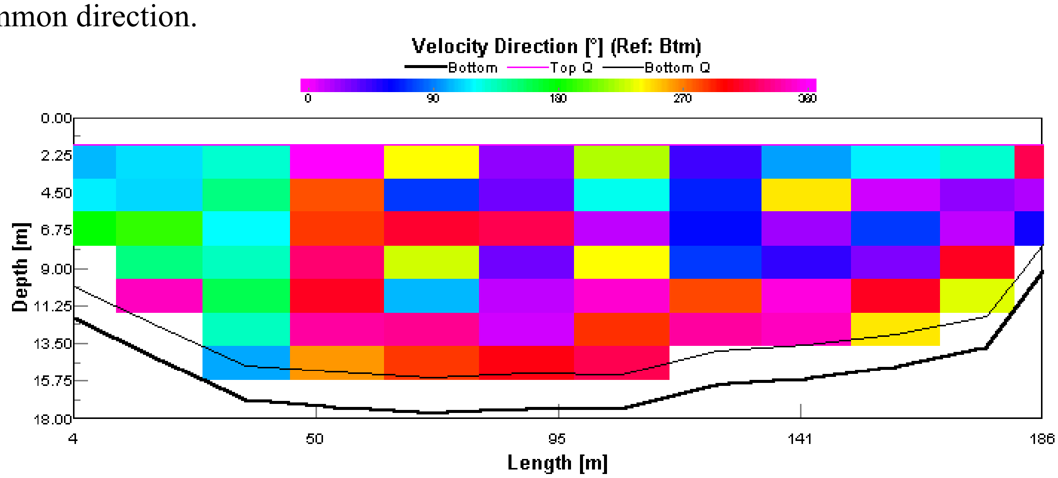

Figure 5-53
Transect 20, Velocity Direction Contour Plot

From these types of data, producing regions of common flow direction, many core flow criteria were met, even though a single ensemble in another region of the transect may have produced a higher velocity.

Transect 18 was again too shallow to collect usable data. Transect 23 was not surveyed.

Wind Effects
Wind speeds were strong to severe during two of the three days of data collection on Lake Belton. This created a wave chop, which produced chaotic flow patterns, as in **Figure 5-54**, in the shallower lake sections.

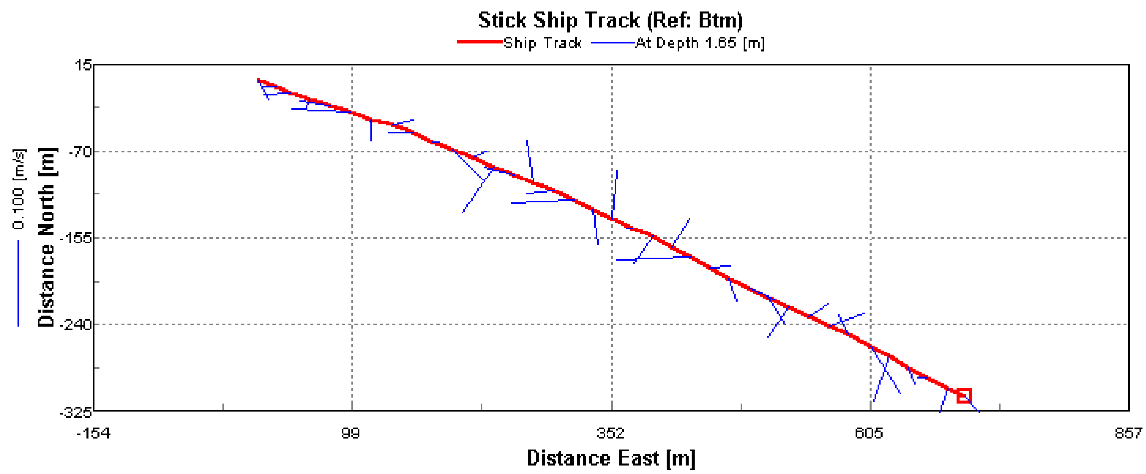

Figure 5-54
Surface Wind and Wave Chop Effects, Transect 16

Eddy Conditions
Complex eddy conditions were observed in several transects. Often, more than one reverse (eddy) flow pattern was recorded across a transect. In **Figure 5-55**, nearly the entire transect is an eddy feature, with similar velocity near each bank.

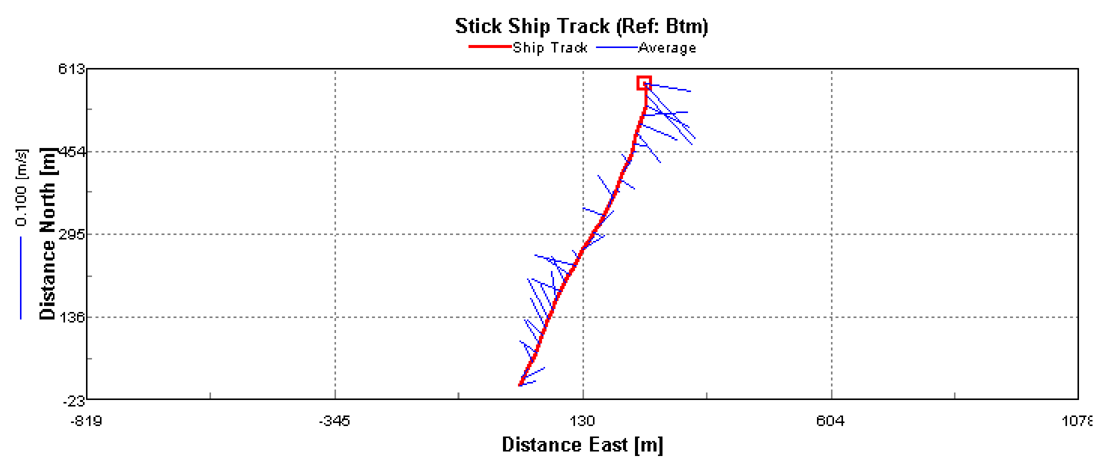

Figure 5-55
Large Eddy Feature Spanning Lake Channel, Transect 14

The following data examples of Transect 13 illustrate a diagonal shear associated with an eddy flow pattern (**Figure 5-56**, **Figure 5-57**).

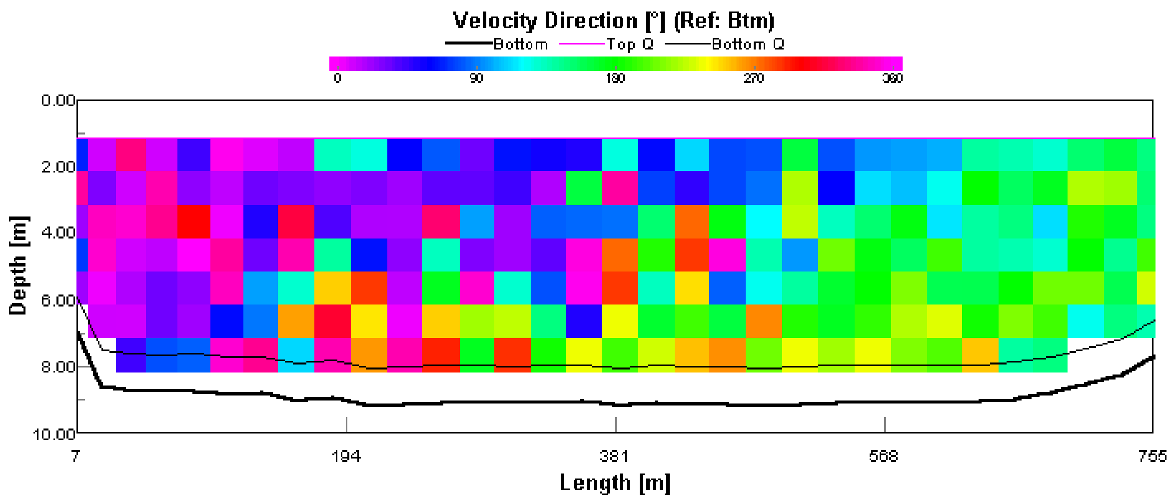

Figure 5-56
Diagonal Shear with Reverse Flow on Upper Left and Lower Right, Transect 13

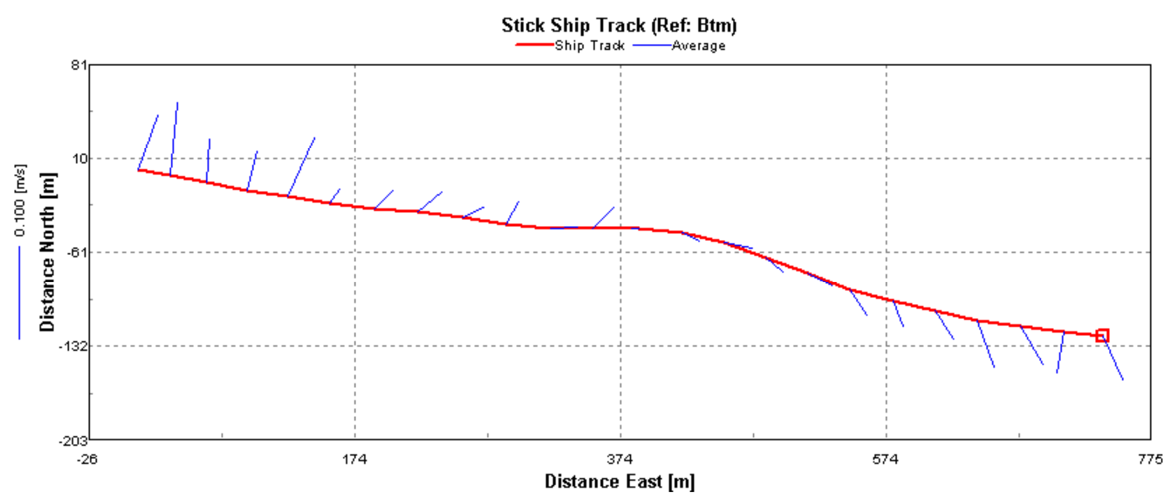

Figure 5-57
Vector Flow Diagram of Eddy Flow, Transect 13

Discharge

Discharge measurements varied greatly from transect to transect and should not be considered an indication of true lake flow. The discharge values present the general trend for the moments of the transects, at that location, and may be dominated by factors outlined below.

As with the previous surveys, measured discharge values are not likely to be accurate due to several factors including:

- Variations in wind driven circulation on the same time scale as the period of the transect.
- Extremely low flow conditions.
- Eddy conditions with shifting centers of circulation on the same time scale as the period of the transect.
- Wind driven surface currents greatly exceeding core flow, which may indicate lake discharge.

Discharge values are derived from data across the entire transect, bi-layer flow could produce low discharge values due to the canceling effect of opposing flow directions.

An area of laminar flow, possibly indicating discharge, is apparent on Transect 1, in the deepest section of the water column (**Figure 5-58**).

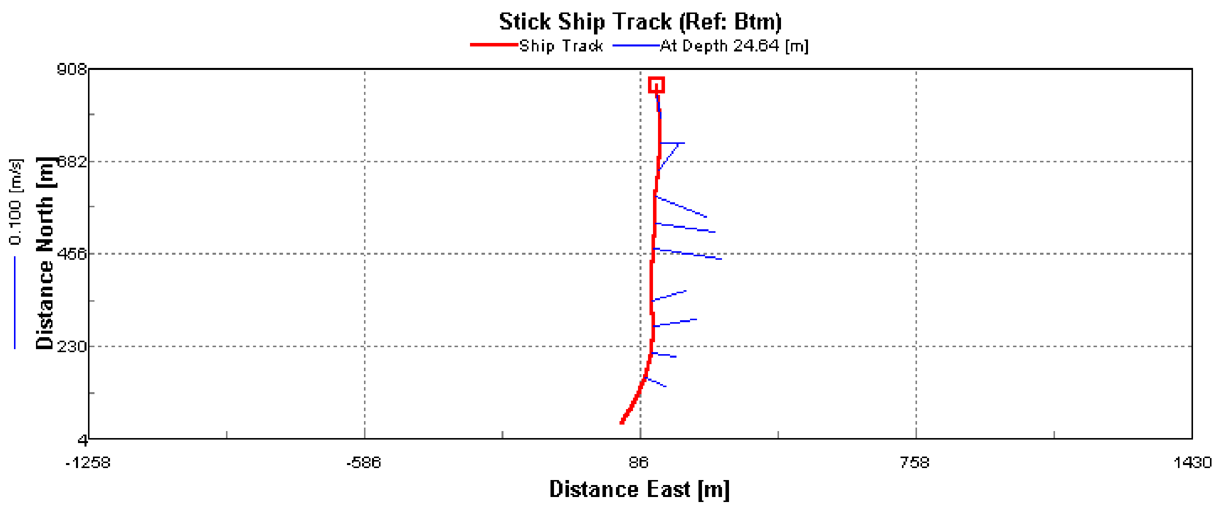

Figure 5-58
Vector Flow Diagram of Laminar Channel Flow at 24.64m Depth, Transect 1

Thalweg Flow
Thalweg flow, although at very low velocity, was detected in transects 6 and 7. Transect 6 reveals low velocity thalweg flow beneath very chaotic upper water flow (**Figure 5-59**); while Transect 7 produced thalweg flow as the lower half a nearly consolidated two layer flow pattern (**Figure 5-60**).

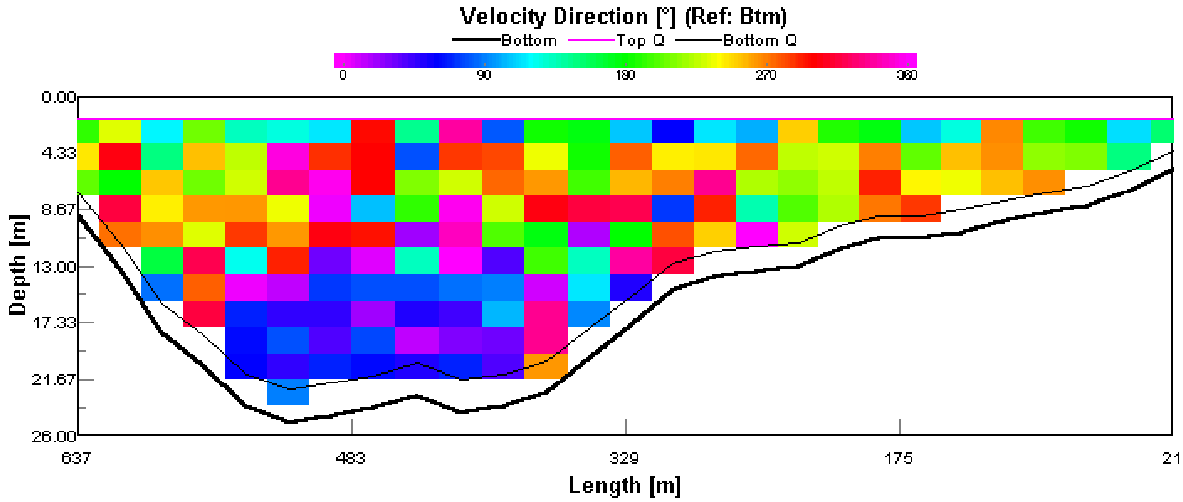

Figure 5-59
Thalweg Flow, Transect 6

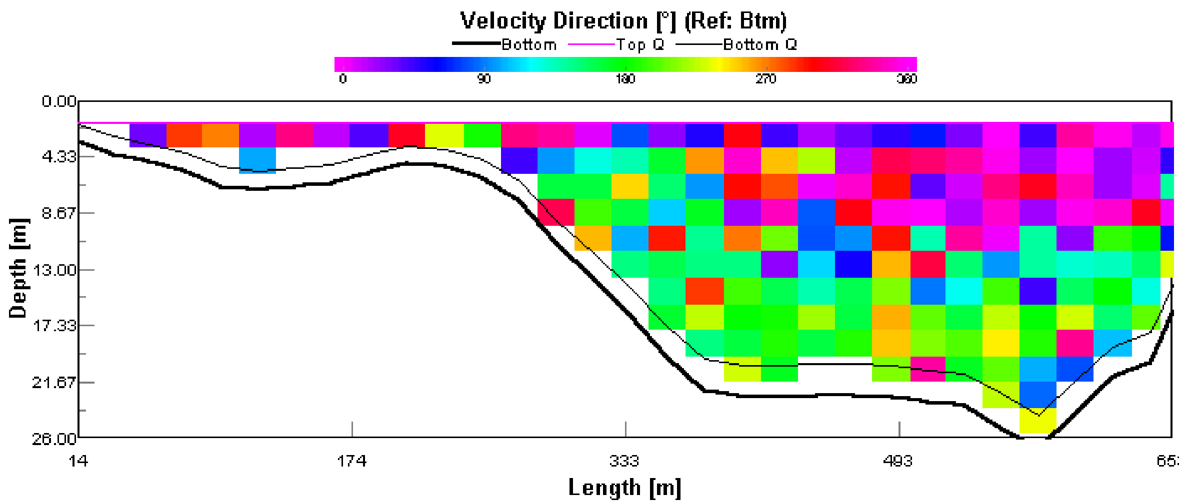

Figure 5-60
Thalweg Flow, Transect 7

Temperature

Temperature profiles at all sites indicate that the lake channels were well mixed, and that a thermocline was not present. Temperature measurements south of Transect 15 ranged from 12 ° C to 14.5 ° C. Measurements north of Transect 15 were slightly lower, ranging from 10.5° C to just above 13 ° C.

<u>*5.1.4.2.3.5 Overall Evaluation*</u>

Currents

Currents measured in Lake Belton were consistently low throughout the year, with maximum core flows not exceeding 0.3 m/s. Lake water levels were the highest during the June 2003 survey, and were the lowest during the September 2003 survey, leading to difficulties collecting data in shallow areas. Areas of measurable flow in June, such as the

Leon River Transect 22, were nearly impassable in December 2003 and produced data of limited value. Transect 18 was too shallow to collect usable data during all but the June survey.

Laminar Flow. During the June, 2003 survey, transect 22 showed strong laminar stream flow without effects of wind or eddies (**Figure 5-61**).

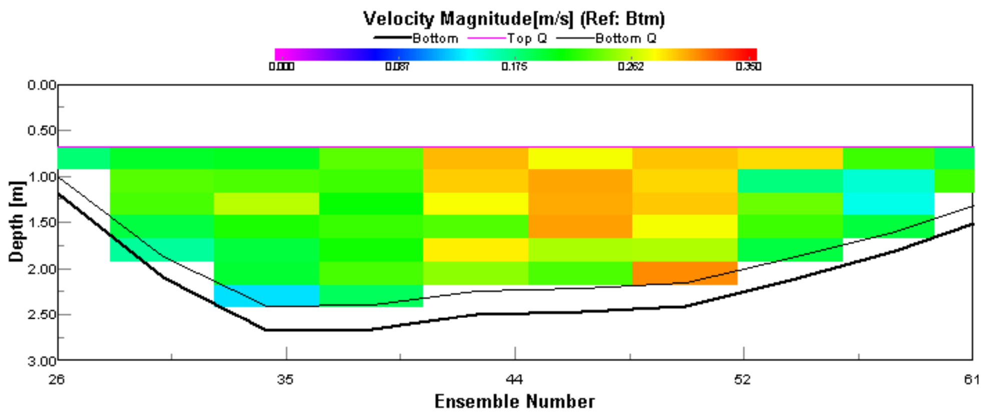

Figure 5-61
Laminar Stream Flow Discharge of 16.3 m^3/s. June 2003 Survey, Transect 22 Leon River Section

Eddy Conditions. Complex eddy conditions with diagonal shear layers across the channel were observed during the June, September, and December, 2003 surveys, even in spite of extremely low flow conditions during the September, 2003 survey. Often, more than one reverse (eddy) flow pattern was recorded across a transect. In the example below (**Figure 5-62**), nearly the entire transect is an eddy feature, with similar velocity near each bank. These reverse channel flows were observed in a number of transects, and three examples are shown below (**Figure 5-63**, **Figure 5-64**, and **Figure 5-65**).

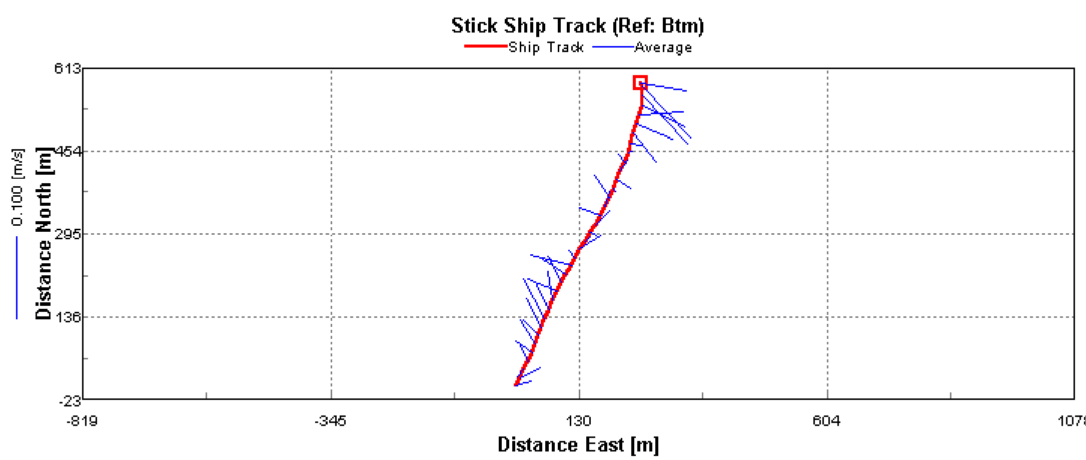

Figure 5-62
Large Eddy Feature Spanning Lake Channel. December 2003 Survey, Transect 14

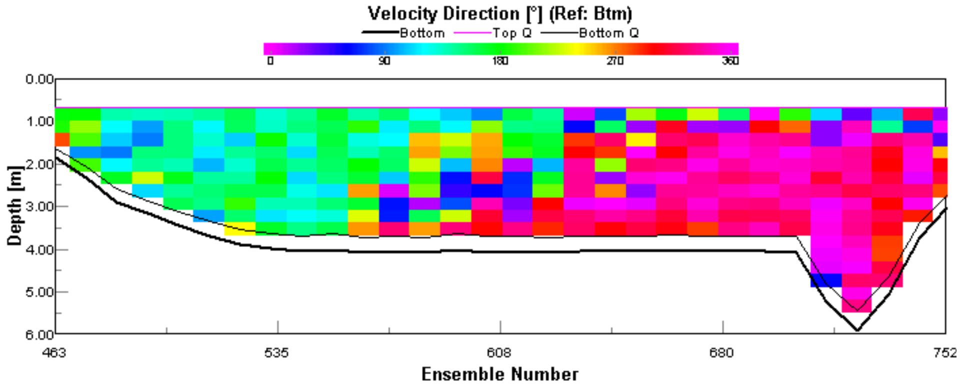

Figure 5-63
Eddy Flow. Diagonal Shear with Reverse Flow on Upper Left and Lower Right. Southward (Green) Northward (Red). June 2003 Survey, Transect 17

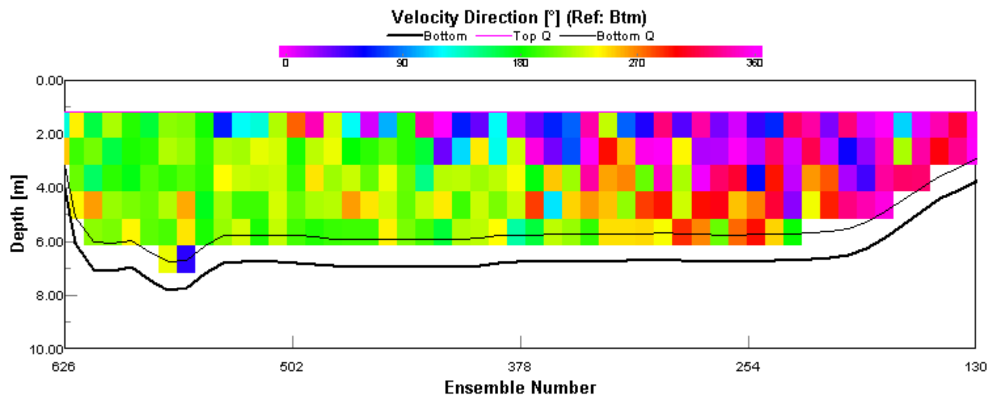

Figure 5-64
Diagonal Shear with Reverse Flow on Upper Right and Lower Left. Southward (Green) Northward (Red). September 2003 Survey, Transect 15.

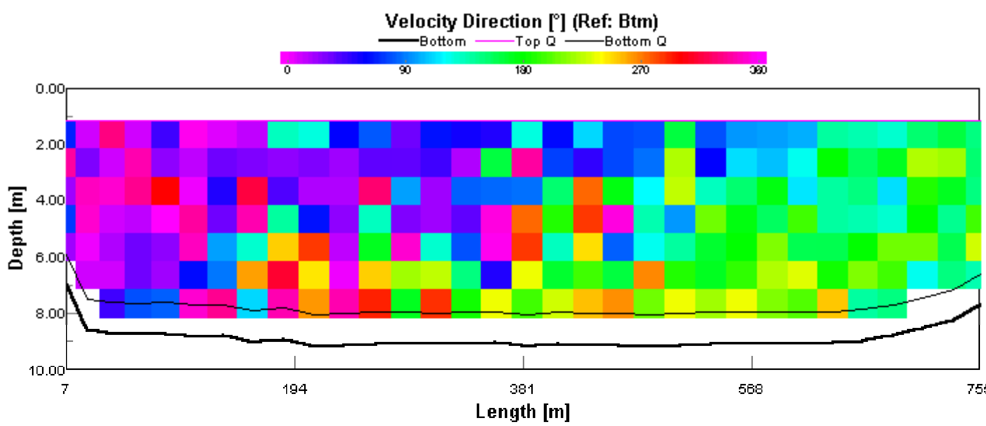

Figure 5-65
Diagonal Shear with Reverse Flow on Upper Left and Lower Right. Southward (Green) Northward (Red). December 2003, Transect 13

Thalweg Flow. Several examples of thalweg flow, or slightly increased flow in the submerged thalweg, were identified during each of the four seasonal current surveys. Two examples are shown below (**Figure 5-66** and **Figure 5-67**)

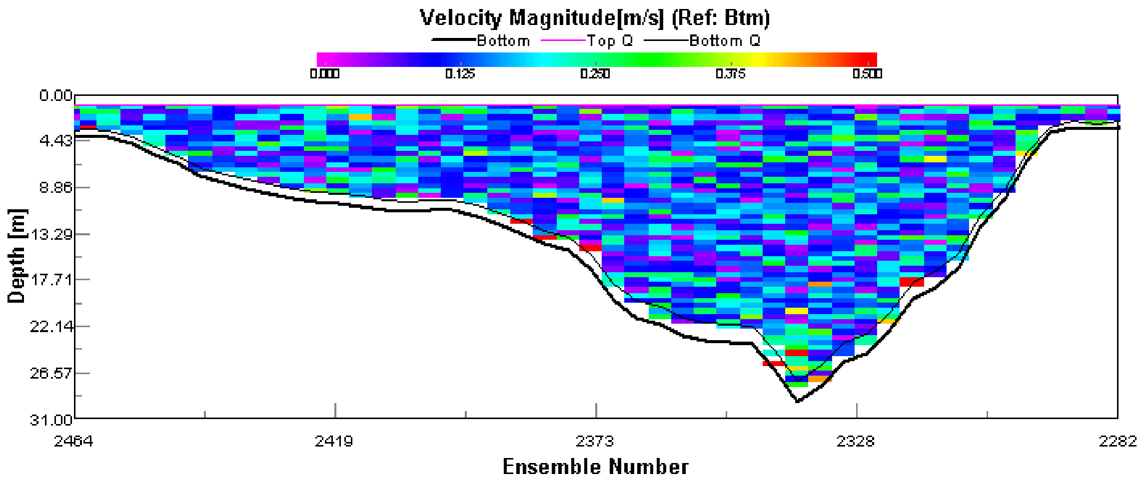

Figure 5-66
Increase Flow in the Bottom of a Thalweg. March 2003 Survey, Transect 6

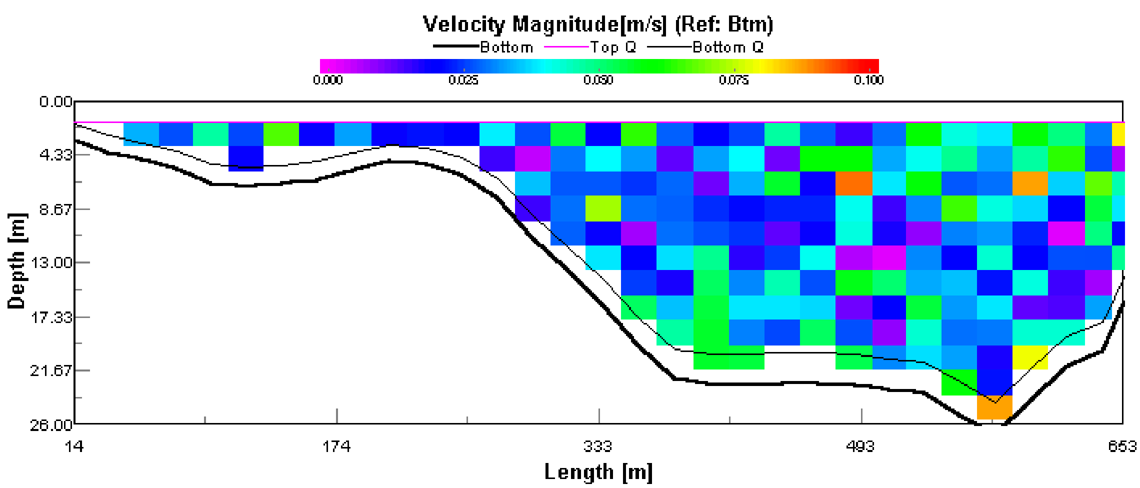

Figure 5-67
Increased Flow in the Bottom of a Thalweg. December 2003 Survey, Transect 7

Core Flow Outside Thalweg. Some transects showed a distinct flow core in mid-channel, outside the thalweg (**Figure 5-68** and **Figure 5-69**).

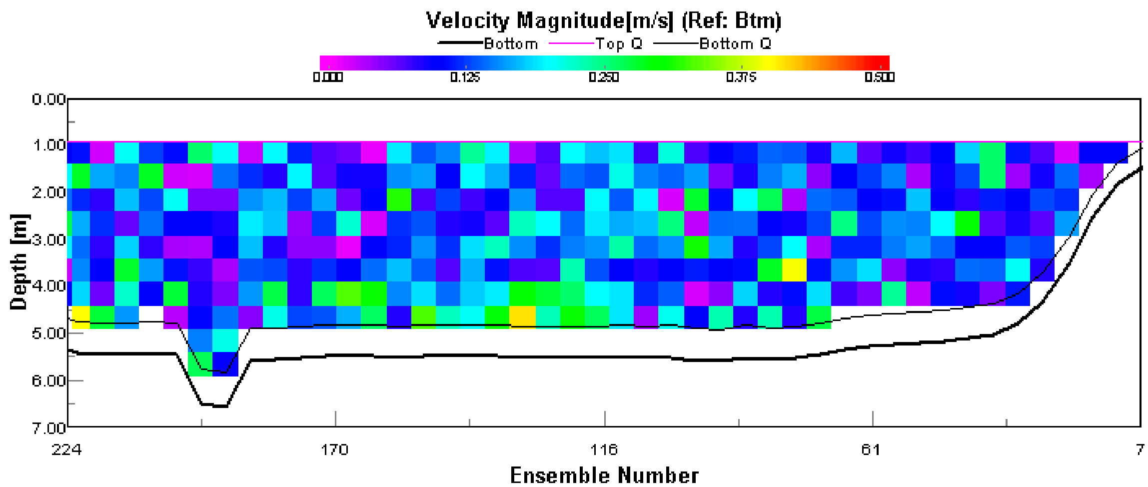

Figure 5-68
Channel Center Flow Adjacent to Thalweg. March 2003 Survey, Transect 16

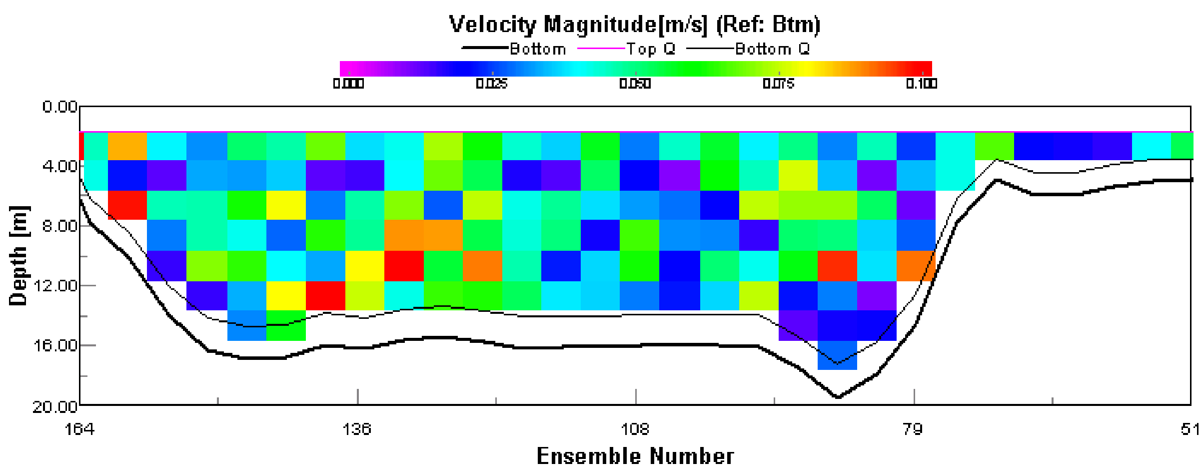

Figure 5-69
Channel Center Flow Adjacent to Thalweg. September 2003 Survey, Transect 10

Uniform Flow. Many transects show uniform magnitude fields of weak and variable flow (**Figure 5-70**). This was a consistent feature in each of the four surveys.

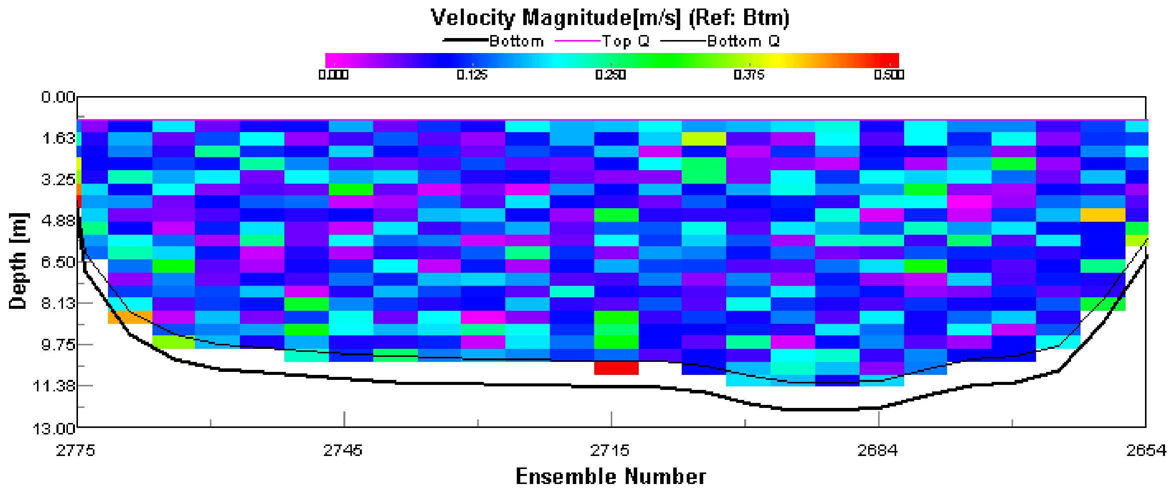

Figure 5-70
Weak and Variable Uniform Flow. March 2003 Survey, Transect 12

Seasonal Flow Comparison. Data were examined for seasonal trends, and little to no correlation was found between the four surveys. Due to extremely low current velocities found throughout the year, data indicate that external forces such as the adjacent landmass and wind speed and direction are the primary influences on the currents in Lake Belton.

An example of the influences of adjacent landmasses on the flow patterns of parts of the lake was seen at Transect 15 during each of the four surveys. At this transect, velocity fields were generally weak and inconsistent, however the direction fields reflected consistent eddy formation, evident by a diagonal shear with reverse flow on the upper right and lower left sides of the transect (**Figure 5-64**).

An example of the lack of seasonal correlation was seen at Transect 12. Velocity magnitude and direction profiles from each survey at Transect 12 are shown below for comparison (**Figure 5-71** through **Figure 5-78**). In the example below, it can be seen that trends in the velocity fields were generally weak and inconsistent between surveys (**Figure 5-71**, **Figure 5-73**, **Figure 5-75**, and **Figure 5-77**). Trends in the directional fields showed a tendency for the surface flow to follow the general shape of the surrounding landmass under the influence of the wind, however the overall direction of the flow was not consistent throughout the year (**Figure 5-72**, **Figure 5-74**, **Figure 5-76**, and **Figure 5-78**).

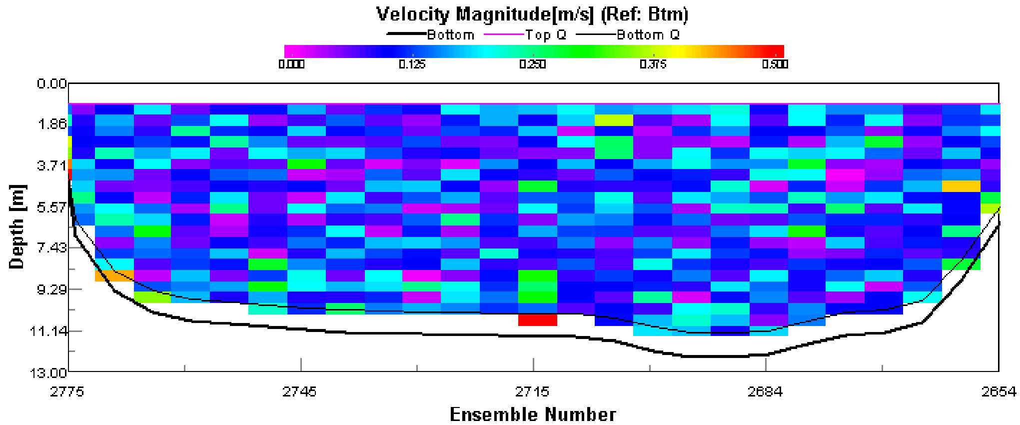

Figure 5-71
Current Velocity During the March 2003 Survey, Transect 12

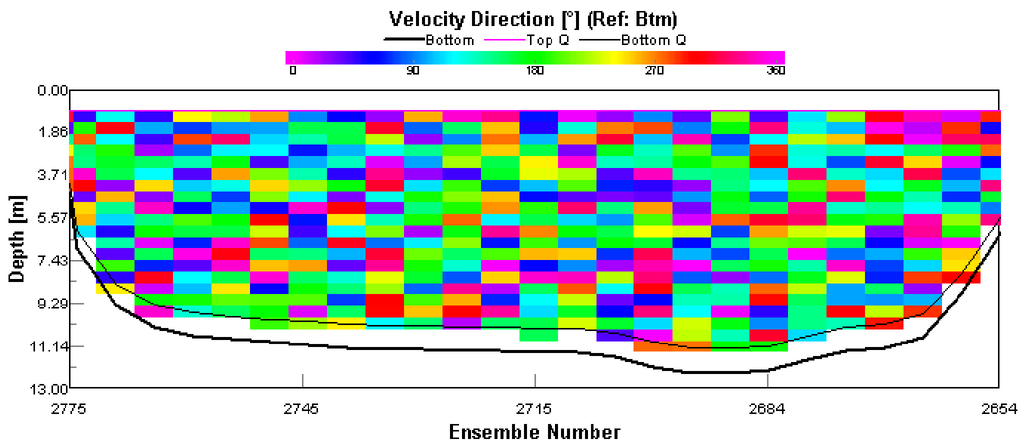

Figure 5-72
Current Direction During the March 2003 Survey, Transect 12

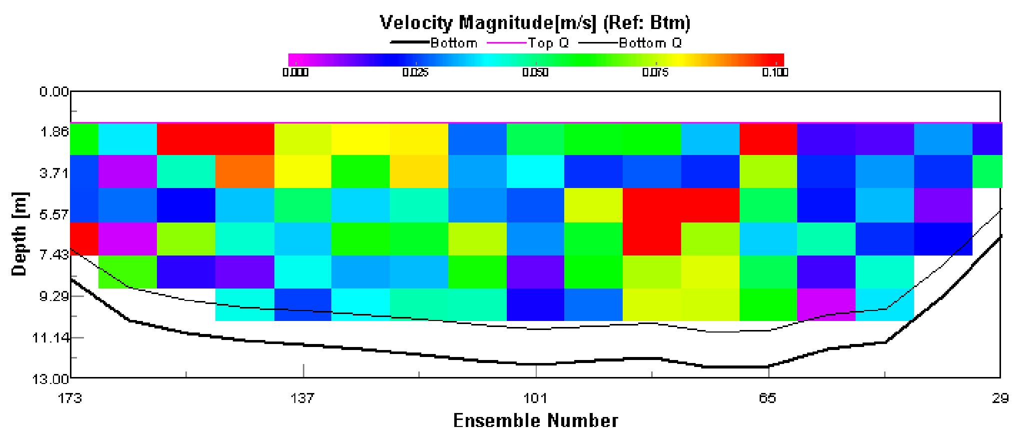

Figure 5-73
Current Velocity During the June 2003 Survey, Transect 12

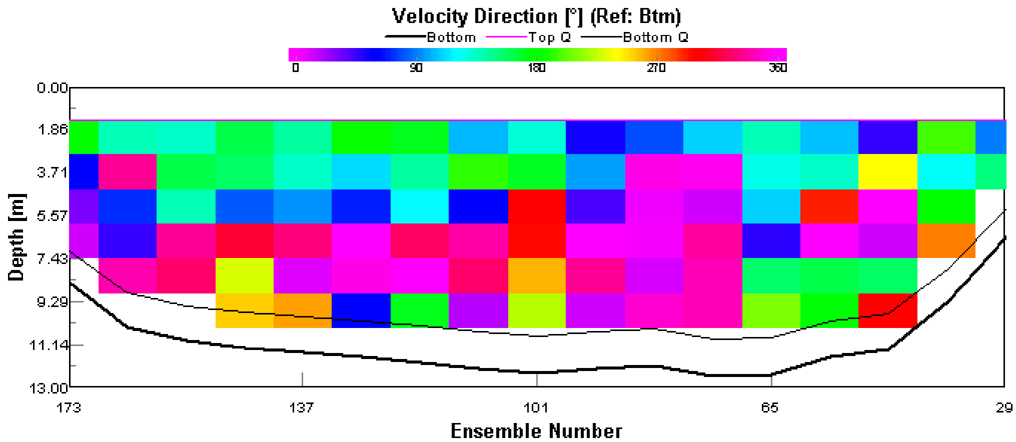

Figure 5-74
Current Direction During the June 2003 Survey, Transect 12

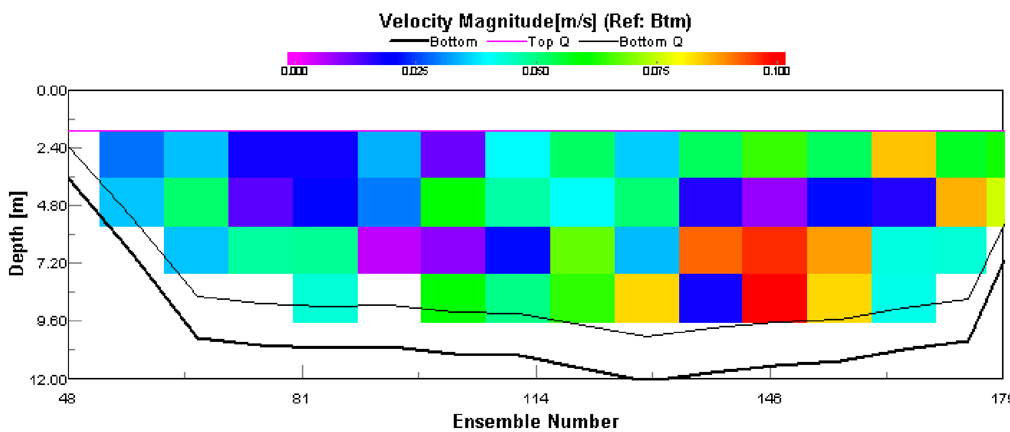

Figure 5-75
Current Velocity During the September 2003 Survey, Transect 12

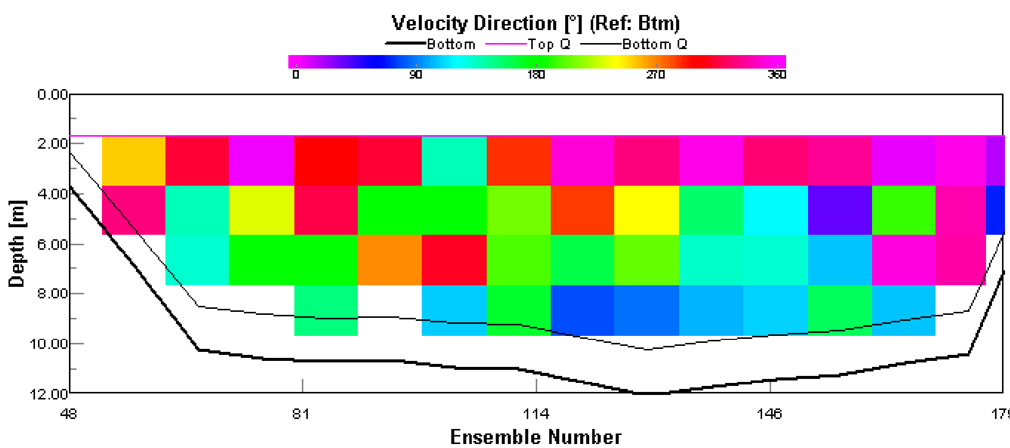

Figure 5-76
Current Direction During the September 2003 Survey, Transect 12

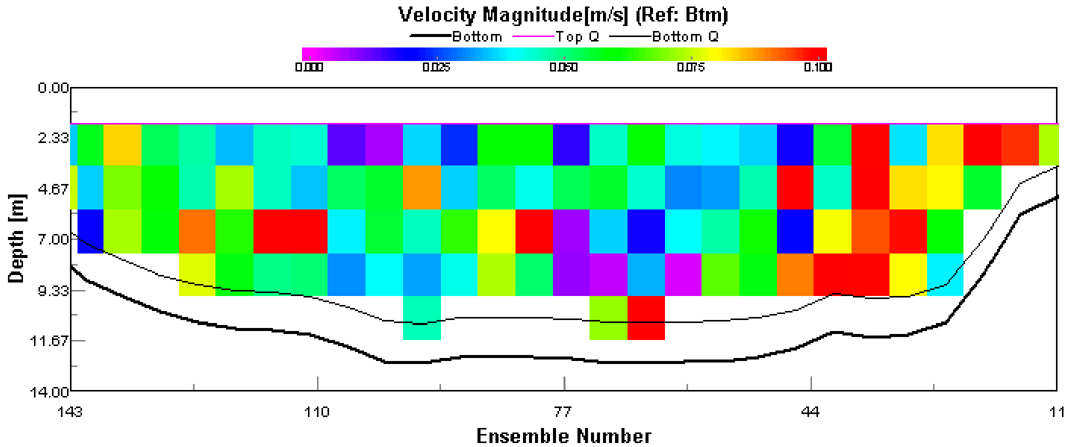

Figure 5-77
Current Velocity During the December 2003 Survey, Transect 12

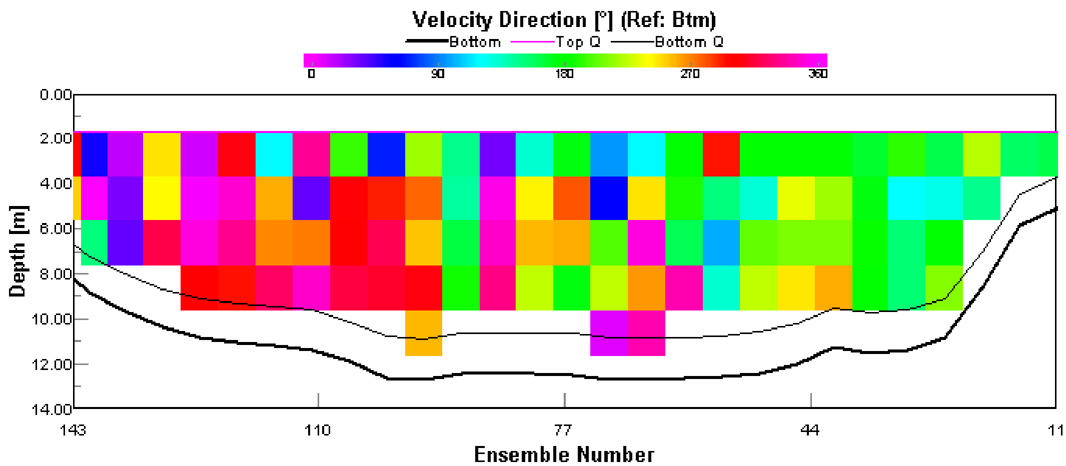

Figure 5-78
Current Direction During the December 2003 Survey, Transect 12

<u>Wind Effects.</u> Wind speeds were generally light during the survey period. Wind speeds were strong to severe during two days of the December 2003 survey period leading to noisy surface data. Wind speeds were generally light during the September 2003 survey period. Some instances of wind effect correlate to periods of building breeze during a given transect (**Figure 5-79**). Wind directions varied with location possibly due to the effects of the high channel banks on the breeze. These effects seem to cause shore-parallel wind directions regardless of the wind direction at elevations above the channel banks.

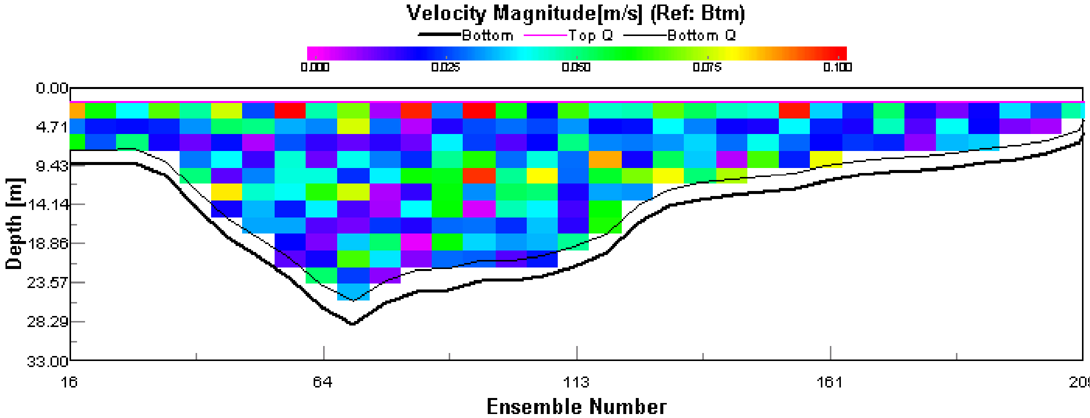

Figure 5-79
Surface Wind Current Effects During Breeze. September 2003 Survey, Transect 6

Discharge
Discharge measurements were frustrated by the extreme low flows. Discharge values measured in the lake channels follow some plausible trends. One additional source of discharge to be considered is the possible existence of submerged springs and seeps.

Summation of this discharge data for any purpose other than very general trend observations with this data is not advisable. Measured discharge values are not likely to be accurate due to several factors including:

- Variations in wind driven circulation on the same time scale as the period of the transect.
- Extremely low flow conditions.
- Eddy conditions with shifting centers of circulation on the same time scale as the period of the transect.

Temperature
Temperature data during the March, June, and September 2003 surveys showed strong thermoclines in areas of vertical multi-layer flow in the southern channels (**Figure 5-80**). Temperature profiles during the December survey, however, indicated that the lake channels were well mixed at all sites, and that a thermocline was not present (**Figure 5-81**).

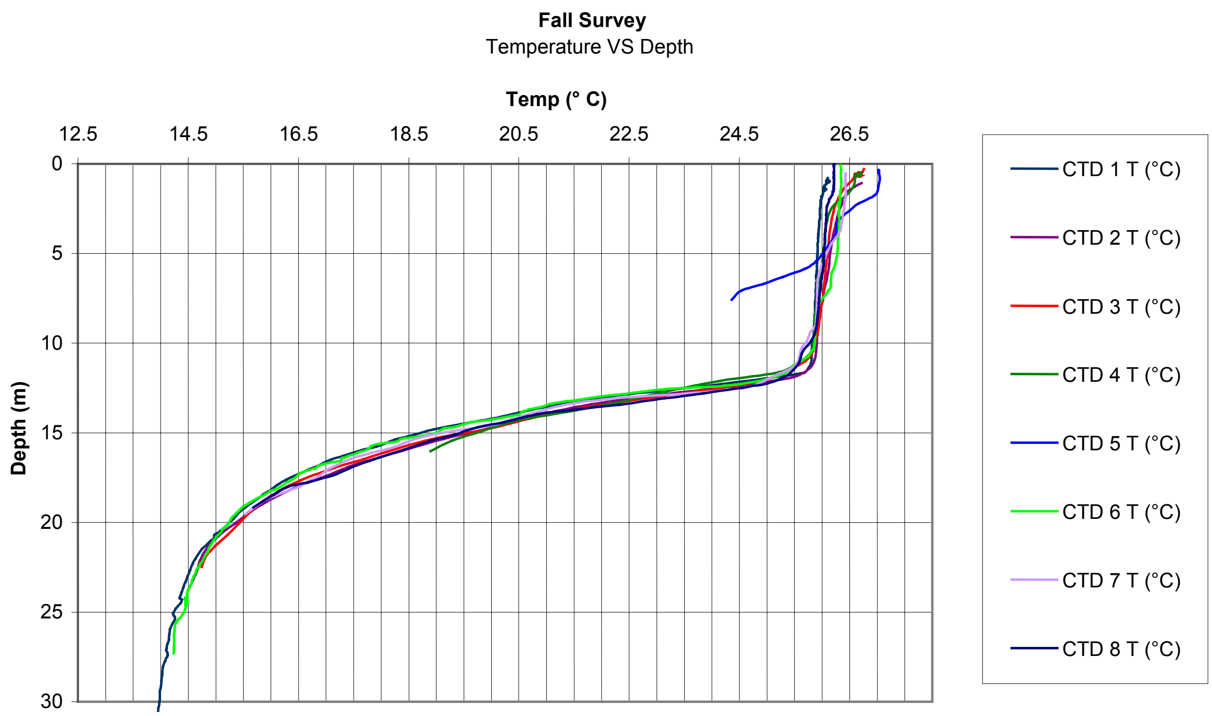

Figure 5-80
Temperature Profiles During the September 2003 Survey

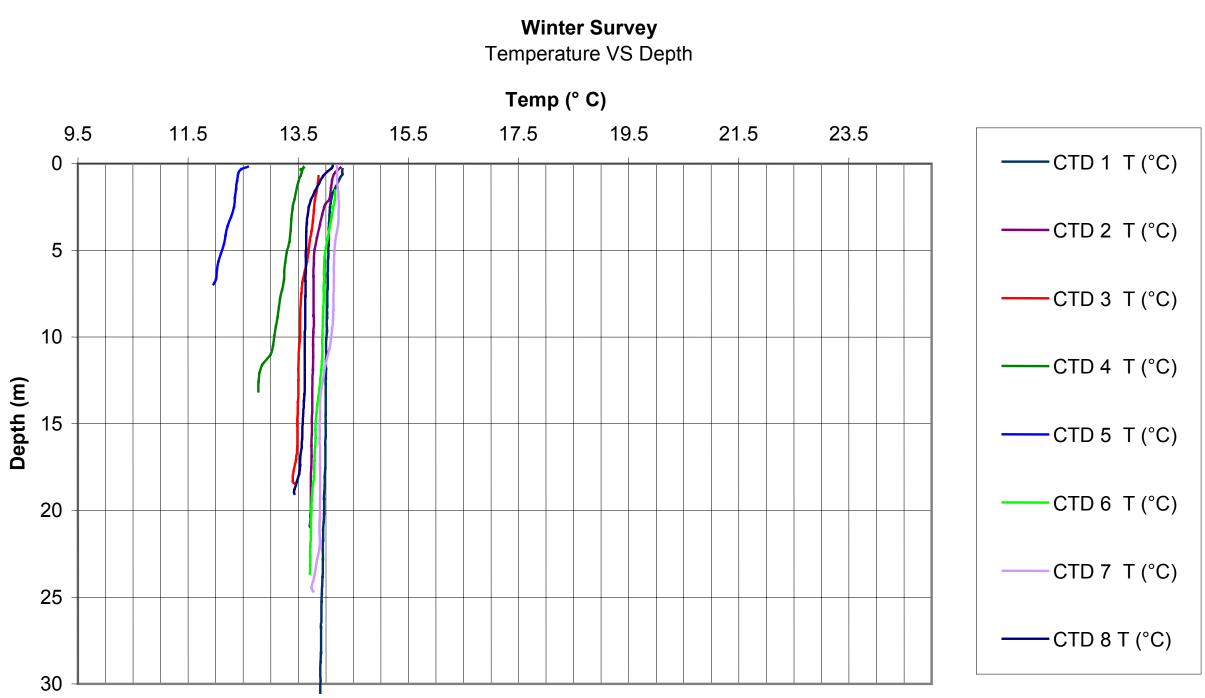

Figure 5-81
Temperature Profiles During the December 2003 Survey

Discussion Summary

For the ADCP Lake-Flow surveys, there is a limitation on the precision of accuracy for the data collected depending on natural lake conditions such as extremely low flows, eddy currents, wind conditions, and small sample volumes throughout a transect cross-section.

The seasonal surveys (spring, summer, fall, and winter) show the varying lake parameters (flow and temperature) throughout the year. Consistent preferential flow and current profiles were not identified during the study. Preferential flow and current profiles were more evident in the spring and summer surveys. Preferential flow and current profiles for the fall survey significantly decreased in comparison due to a lack of significant rain events throughout the summer. Adjacent landmasses were shown to cause the formation of numerous horizontally circulating eddies, which provides a mechanism for mixing the water column. The irregular shape and high banks of the lake tend to create wind-driven surface flow regardless of lakebed bathymetry or any suspected "down-stream" condition. Temperature profiles in the spring showed a well-mixed surface layer with a distinct thermocline between 2-m and 5-m deep at all transects. Summer surface temperatures for lakes and rivers were nearly 22^{o} C warmer than during the spring. Strong thermoclines in the summer were observed at channel transects, at about an 8-m depth. Measurements north of transect 15 were well mixed with no thermoclines evident, possibly due to well-mixed thalwegs. Fall surface temperatures were nearly identical to the summer survey. The thermocline for the fall survey was deeper and more abrupt at 11-m. Measurements north of transect 15 in the fall were without evidence of a thermocline.

In conclusion, preferential flows along the old river channel have not been observed at all transects during any of the four surveys performed. Therefore, thalweg flow does not appear to be present as originally surmised in the CSM.